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ACRONYMS

AMR	Analysis/Model Report
BDCF	Biosphere Dose Conversion Factor
CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
K_d	Soil Solid/Liquid Partition Coefficient
M&O	Management and Operating Contractor
NRC	Nuclear Regulatory Commission
OCRWM	Office of Civilian Radioactive Waste Management System
PA	Performance Assessment
SZ	Saturated Zone
T-Value	Soil Loss Tolerance Value
TDMS	Technical Database Management System
TIC	Technical Information Center
TSPA&I	Total System Performance Assessment and Integration
TSPA-SR	Total System Performance Assessment - Site Recommendation
TSPA-VA	Total System Performance Assessment - Viability Assessment
USDA	United States Department of Agriculture
USDA NRCS	United States Department of Agriculture Natural Resource Conservation Service
UZ	Unsaturated Zone

1. PURPOSE

This activity will determine reasonable and conservative bounding estimates of annual surface soil removal representative of the major soils present in the vicinity of the projected reference critical group within the Amargosa Valley. Leaching coefficients appropriate for the various radionuclide elements that will be considered in the *Total System Performance Assessment-Site Recommendation* (TSPA-SR) dose calculations carried out in the Repository Integration Program (RIP) code (Golder 1998) will also be determined in the work activity. The analyses are needed to address concerns raised by review groups, including the U.S. Nuclear Regulatory Commission (NRC) and the Performance Assessment Peer Review Panel (PAPRP), and the U.S. Department of Energy (DOE) Management Technical Service (MTS), that the potential impact of radionuclide accumulation in soils subjected to long-term continuous irrigation with contaminated water was not addressed in the *Total System Performance Assessment–Viability Assessment (*TSPA-VA), (CRWMS M&O 1998). The soil removal analysis reported in this Analysis/Model Report are applicable to both existing agricultural and domestic use soils and soils conditions subsequently modified by thin deposits of volcanic ash (i.e., ash deposits less than one centimeter thick); the analysis does not address the future soil conditions resulting from the deposition of thick ash deposits (e.g., >1.0 cm).

The Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) Performance Assessment Organization will use radionuclide-specific biosphere dose conversion factors (BDCFs) to calculate potential radiation doses to a hypothetical human receptor group as part of the post-closure TSPA for the Site Recommendation (SR). Possible effects of soil radionuclide build-up on BDCFs generated by the computer code GENII-S (Leigh et al. 1993) will be evaluated by subsequent analysis, and the soil removal estimates derived from this Analysis/Model Report (AMR) analysis will be used as input for the comprehensive radionuclide build-up assessment. Additionally, the soil loss estimates derived from the analysis will be used in subsequent dose calculations for the radionuclide-contaminated ash deposition scenario. The parameters used to calculate the annual soil depth reduction estimates and radionuclide-element leaching coefficients will be placed in the Technical Data Management System (TDMS) along with required documentation in accordance with AP-SIII.3Q, *Submittal and Incorporation of Data to the Technical Data Management System*.

The two major removal processes evaluated in this analysis are:

1. Surface Soil Erosion Rate. The annual reduction (cm/yr) of surface soil by the combined processes of both wind and water erosion. In this analysis the quantity (kg) of soil removed from a given area (ha) of land per year (yr) will be used to calculate the annual depth (cm) reduction of surface soil.

2. Leaching. The downward movement of substances, including radionuclides, dissolved in percolating waters. In this analysis, the leaching coefficient (λ yr^{-1}) will be determined for 27 different elements.

The purpose for the annual soil depth reduction estimates is to couple these with the radionuclide input quantities from irrigation with contaminated groundwater in a separate abstraction analysis to determine the net build-up (inputs minus outputs) of radionuclides.

The purpose for the leaching analysis is to develop more site-specific values for these parameters than exist as default data in the GENII-S code, i.e., specific for the soil properties and principal land use practices (alfalfa production) existing in the Amargosa Valley. The leaching coefficients derived from this analysis will be used in the development of BDCFs for both the non-disruptive and selected disruptive event scenarios. The 27 elements (isotope independent) considered in the analysis were selected from the list of radionuclide elements modeled in TSPA-VA (CRWMS M&O 1998a) and additional elements subsequently screened-in through an analysis to determine which radionuclides should be included in the total system performance assessment for site recommendation based on their potential contribution to dose (TSPA-SR) calculations (CRWMS M&O 1999a).

In these analyses, two estimates were developed for each of the two processes. First, a "reasonable representative" or "best" estimate was developed for each. This estimate is defined as one being reasonably expected to occur based on the soil properties and land use characteristics of the critical group (Dyer 1999, Section 115) proposed by the Nuclear Regulatory Commission (NRC) (64 FR 8640). The conservative bounding estimate is a "high dose-yielding bounding value" calculated under the conditions that would potentially result in higher exposure rates. These analyses were conducted according to the Development Plan entitled *Evaluation of Soil/Radionuclide Removal by Erosion and Leaching, Rev. 0,* (CRWMS M&O 1999b).

The soil removal analysis is constrained by the assumption that current land use practices result in annual soil depletion due to accelerated erosion (Section 5.1) and does not consider possible accretion due to aeolian and/or alluvial processes that might result in transport of soil material and/or radionuclide contaminants to the site of consideration. Both the soil removal estimates and the calculated leaching coefficients are limited to sandy-textured soils and are therefore not applicable to finer-textured soils that might be present as minor inclusions in the soil mapping units considered in the analyses.

2. QUALITY ASSURANCE

This AMR has been determined to be Quality Affecting in accordance with QAP-2-0, *Conduct of Activities*. The activity evaluation (CRWMS M&O 1999c) determined that the information will be used to support Performance Assessment and it supports other quality-affecting activities. Therefore, this AMR is subject to the requirements of the *Quality Assurance Requirements and Description* (QARD) document (DOE 2000).

Preparation of the AMR did not require the classification of items in accordance with CRWMS M&O procedure QAP-2-3, *Classification of Permanent Items*. The analyses conducted were not field activities. Therefore, a Determination of Importance Evaluation in accordance with CRWMS M&O procedure NLP-2-0 *Determination of Importance Evaluations* was not required. The governing procedure for preparation of this AMR is OCRWM procedure AP-3.10Q, *Analyses and Models.*

3. COMPUTER SOFTWARE AND MODEL USAGE

No models were used or developed in this analysis. The leaching analyses included the use of a FORTRAN routine (consisting of several modules) developed in accordance with AP-SI.1Q, *Software Management* (Section 5.1, Control of Software Routines and Macros). The software routine developed, SOIL_MODEL, version A1.20, was developed with FORTRAN 77. Attachment II includes the Software Routine Verification documentation (McCurley 1999a) and a hard-copy of the routine's source code listing (McCurley 1999b). The routine was used with specific values of input parameters (Tables 2 and 3, all positive numbers). As can be readily verified by executing Equation 1 (Section 6.2) with the use of a hand calculator, the macro produces the correct results for all specified input parameters.

4. INPUTS

4.1 DATA AND PARAMETERS

The following two sections contain a brief summary and listing of the input data and parameters used in the calculations for the analysis of the two radionuclide removal processes from the surface soil.

4.1.1 Surface Soil Erosion Analysis – Data/Parameter Inputs

Soil loss tolerance (*T*), sometimes called permissible soil loss, is defined as the maximum annual rate of soil erosion that can occur while still maintaining productivity indefinitely (Troeh et al. 1980, p. 149). *T*-value indices have been established for all major soils occurring across the United States to serve as a guideline for land owner/managers to manage their practices in such a manner as to sustain agricultural production over time. A single *T*-value is assigned to each soil type, or soil series (Brady 1984, p. 434) occurring within an agricultural field or applicable land unit. The soil's surface horizon bulk density was employed to calculate the mass quantity of annual soil loss per unit area of land (represented by the *T*-value) to an annual soil depth reduction (Section 6.1.1).

Table 1 lists *T*-values and soil bulk density value ranges for the soils occurring in the major mapping units in the vicinity of Lathrop Wells, NV which is the location of the specified farming critical group (Dyer 1999, Section 115 – Required characteristics of the reference biosphere and critical group). These soil data were extracted from a database maintained at the Las Vegas, NV field office of the U.S. Department of Agriculture Natural Resource Conservation Service (SN9912USDASOIL.000). The six soil series comprising the specific mapping units were taken from existing soil maps of the Amargosa Valley (CRWMS 1999c, Figure 1, pp. 2-3). Assumptions and justification for the use of these input parameters are discussed in Section 5.1.

4.1.2 Leaching Analysis – Data/Parameter Inputs

The soil bulk density *(ρ)* input parameter value used in the leaching coefficient calculations (Table 2) is the approximate mean value of the soil bulk density range associated with all six soils listed in Table 1. The annual precipitation *(P)*, annual irrigation *(I)*, and annual evapotransporation *(E)* input parameter values are those values associated with alfalfa production in the Amargosa Valley. The element-specific soil/liquid partition coefficients (K_d values) listed in Table 3 are the values recommended by Sheppard and Thibault (1990, Tables 1, 3, and A-1) for sandy loam-textured soils. Justification for the use of these inputs, as well as assumptions on their appropriateness for use in the analysis, are discussed in Section 5.2.

Table 1. Soil Loss Tolerance *(T)* and Surface Horizon Soil Bulk Density *(ρ)* Values Assigned to the Soil Series Comprising the Mapping Units Used for Agricultural Production in the vicinity of Lathrop Wells, NV.

Soil Series[a]	Soil Loss Tolerance Factor, *(T)* (t/ ha/yr)	Soil Bulk Density *(ρ)* [b] (g/cm^3)	DTN
Arizo	11.21	1.40 – 1.55	SN9912USDASOIL.000
Commski	11.21	1.40 – 1.60	SN9912USDASOIL.000
Corbilt	8.97	1.35 – 1.50	SN9912USDASOIL.000
Sanwell	11.21	1.40 – 1.60	SN9912USDASOIL.000
Shamock	4.48	1.50 – 1.70	SN9912USDASOIL.000
Yermo	11.21	1.40 – 1.60	SN9912USDASOIL.000

Notes: [a] Data extracted from CRWMS M&O (1999c), Figure 1, pp. 2-3 and Appendix C.

[b] DTN SN9912USDASOIL.000, Moist Soil Bulk Density Value.

Table 2. Summary of Generic (e.g., not radionuclide-specific) Inputs Used in the Leaching Analysis

Analysis Parameter	Input	DTN
Soil Bulk Density *(ρ)*	1.50 g/cm^3 [a]	SN9912USDASOIL.000
Annual Precipitation *(P)*	10.24 cm/yr [b]	MO9903CLIMATOL.001
Irrigation Rate *(I)*	240.44 cm/yr [c]	MO9912SPAING06.033
Annual Evapotranspiration *(E)*	235.43 cm/yr [d]	MO9912MWDEEA06.003

NOTES: [a] Mean value used as a “generic” soil bulk density for the purpose of this analysis. The value is calculated by summing the mid-range values for all six soil series listed in Table 1 and taking the average of these six values.

[b] Value is calculated by summing the average monthly precipitation (inches) for Site 9 listed in MO9903CLIMATOL.001 and multiplying by 2.54 for conversion to metric units (cm).

[c] Value is calculated by multiplying the *Milk (Alfalfa) Irrigation Rate* parameter (94.66 inches) listed in MO9912SPAIN06.033 by 2.54 for conversion to metric units (cm).

[d] Value is calculated by multiplying the *Annual Evapotranspiration* parameter (92.69 inches) listed in MO9912MWDEEA06.003 by 2.54 for conversion to metric units (cm).

Table 3. Radionuclide Element-Specific Soil Solid/Liquid Partition Coefficients, K_d values, Used in the Calculation of Leaching Coefficients.

Element	K_d (Best Estimate) (L/kg)	K_d (Conservative Estimate) (L/kg)	DTN and Source Table
C	5.00E+00	7.10E+00	SN0002KDVALUES.000, Tables 1 & A-1
Ni	4.00E+02	3.60E+03	SN0002KDVALUES.000, Table 3
Se	5.50E+01	7.00E+01	SN0002KDVALUES.000, Table 3
Sr	1.50E+01	1.90E+02	SN0002KDVALUES.000, Table 3
Y	1.70E+02	— [a]	SN0002KDVALUES.000, Table 1
Mo	1.00E+01	5.20E+01	SN0002KDVALUES.000, Table 3
Zr	6.00E+02	— [a]	SN0002KDVALUES.000, Table 1
Nb	1.60E+02	— [a]	SN0002KDVALUES.000, Table 1
Tc	1.00E-01	1.60E+01	SN0002KDVALUES.000, Table 3
Pd	5.50E+01	— [a]	SN0002KDVALUES.000, Table 1
Sn	1.30E+02	— [a]	SN0002KDVALUES.000, Table 1
Sb	4.50E+01	— [a]	SN0002KDVALUES.000, Table 1
I	1.00E+00	8.10E+01	SN0002KDVALUES.000, Table 3
Cs	2.80E+02	1.00E+04	SN0002KDVALUES.000, Table 3
Sm	2.45E+02	— [a]	SN0002KDVALUES.000, Table 1
Pb	2.70E+02	1.40E+03	SN0002KDVALUES.000, Table 3
Bi	1.00E+02	— [a]	SN0002KDVALUES.000, Table 1
Po	1.50E+02	7.02E+03	SN0002KDVALUES.000, Table 3
Ra	5.00E+02	2.10E+04	SN0002KDVALUES.000, Tables 1 & A-1
Ac	4.50E+02	— [a]	SN0002KDVALUES.000, Table 1
Th	3.20E+03	1.50E+05	SN0002KDVALUES.000, Table 3
Pa	5.50E+02	— [a]	SN0002KDVALUES.000, Table 1
U	3.50E+01	2.20E+03	SN0002KDVALUES.000, Table 3
Np	5.00E+00	3.90E+02	SN0002KDVALUES.000, Table 3
Pu	5.50E+02	3.60E+04	SN0002KDVALUES.000, Table 3
Am	1.90E+03	3.00E+05	SN0002KDVALUES.000, Table 3
Cm	4.00E+03	2.30E+04	SN0002KDVALUES.000, Table 3

NOTE: [a] Conservative Estimate Not Reported by Sheppard and Thibault (1990, Tables 1, 3, and A-1).

4.2 CRITERIA

There are no criteria that are directly applicable to the analyses addressed in this AMR. However, the NRC's Total System Performance Assessment and Integration (TSPA&I) Issue Resolution Status Report (IRSR) (NRC 1998) establishes generic technical acceptance criteria considered by the NRC staff to be essential to a defensible, transparent, and comprehensive assessment methodology for the repository system. These regulatory acceptance criteria address five fundamental elements of the U.S. Department of Energy's (DOE's) TSPA model for the Yucca Mountain site, namely:

1. Data justification (focusing on sufficiency of data to support the conceptual basis of the process model and abstractions)

2. Data uncertainty and verification (focusing on technical basis for bounding assumptions and statistical representations of uncertainties and parameter variabilities)

3. Data uncertainty (focusing on alternative data consistent with available site data)

4. Data verification (focusing on testing of model abstractions using detailed process-level models and empirical observations)

5. Integration (focusing on appropriate and consistent coupling of abstractions).

Relevant to the topic of this AMR, elements (1) through (4) of the acceptance criteria are addressed herein and/or in the supporting calculation document(s). Element (5) of the NRC acceptance criteria, which strictly applies to the completed synthesis of process-level models and abstractions, will be addressed separately in the TSPA-SR.

This AMR was prepared to comply with the above NRC TSPA&I acceptance criteria, as well as the DOE interim guidance (Dyer 1999).

4.3 CODES AND STANDARDS

This is not applicable to this report because there are no codes and standards that apply to the analyses addressed in this AMR.

5. ASSUMPTIONS

5.1 SURFACE SOIL EROSION ANALYSIS

It is assumed that soil erosion rates are accelerated in land subjected to use for agricultural and/or domestic purposes. Under natural conditions the rate of soil removal by erosion is generally in approximate equilibrium with the rate of soil formation from the transformation of underlying bedrock, alluvium, colluvium or other material constituting the parent material. Under these conditions the soil depth (or thickness) is maintained at a near constant depth (Troeh et al. 1980, p. 4). Anthropogenic activities, including tilling of cropland, removal of vegetation, and grazing of pasture or rangeland, typically tend to accelerate the natural rate of soil removal for a given environment. The disturbed soil is left with less protection against the detaching action of raindrop impact and the transporting action of runoff water and wind. Thus, the formation of new soil cannot keep pace with the accelerated erosion rate and the soil material progressively becomes thinner until a new equilibrium is established or the soil material is removed entirely (Troeh et al. 1980, pp. 5-6). A general consequence of accelerated soil erosion is a decline in plant growth and productivity. Although production can at times be maintained with the addition of fertilizers or other costly management practices, the soil's natural production potential declines because the shallower soil has lower water storage capacity, reduced capacity to accommodate plant root growth, and lower fertility status than it did prior to accelerated erosion.

Soil that is continuously irrigated with radionuclide-contaminated water will experience a progressive increase in radioactivity if soil and associated radionuclides are not removed by erosion and leaching. However, soil erosion rates on agricultural land within the Amargosa Valley are accelerated to various degrees, with rates dependent upon the various land use patterns (types of crops grown) and management techniques practiced by the land owners. Therefore, to adequately assess the degree of build-up in radioactivity in soils subjected to continuous or repetitive irrigation with contaminated water, an estimate of concurrent soil loss by erosion is needed.

Over the past several decades, methods of evaluating the effectiveness of erosion control methods have developed with the desired objective of encouraging conservation practices that would reduce soil erosion losses to tolerable rates (Wischmeier and Smith 1978; Woodruff and Siddoway 1965; Yoder and Lown 1995). Tolerable soil loss rates (*T*-values) are defined as the maximum annual rates of soil erosion that will permit the indefinite maintenance of productivity (Troeh et al. 1980, pp. 147-150). Annual soil loss beyond the *T*-value will compromise long-term productivity because this may result in significant reduction in plant nutrients and gully formation and sedimentation may hamper tillage operations. Troeh et al. (1980, p. 149) identified the five levels of soil erosion tolerance established by the USDA Natural Resource Conservation Service (formerly the Soil Conservation Service) based upon the properties of the soils and their resiliency to productivity decline upon erosion; these annual soil erosion tolerance loss groups are equal to about 2, 5, 7, 9, and 11 t/ha. The maximum tolerable loss (11 t/ha/yr) is for deep, permeable, well-drained, productive soils. These soils can tolerate greater rates of surface soil loss and still sustain their productive nature. At the other end of the spectrum, the 2 t/ha/yr soil loss tolerance rate corresponds to shallow soils with unfavorable subsoils and parent materials that severely restrict root penetration and soil development to offset the surface soil losses; these soils cannot sustain even moderate rates of soil erosion and still maintain their productivity.

Guidance and assistance with the implementation of conservation practices are available to agricultural land users within the State of Nevada from the various county agricultural extension services and the USDA NRCS in an effort to curb annual soil losses through erosion. In particular, USDA-sponsored Soil and Water Conservation Districts were set up in each county, or portion of a county, across the United States, as a result of the Soil Conservation and Domestic Allotment Act of 1935, Public Law 74-46. The primary objective of these local Conservation Districts is to offer a broad program of assistance in soil and water conservation on the land and thereby foster the judicious use of land resources.

In this analysis, the *T*-value has been selected as a reasonable representation of the "worst-case" annual soil loss rate from Amargosa Valley land subjected to agricultural or other uses such as domestic/recreational activities. This assumption is justified because the current practice in agricultural communities is to manage soil resources in such a manner as to sustain long-term productivity (USDA NRCS 1998) and therefore restrict annual erosion losses to levels well below the established *T*-values.

For the conservative bounding estimate, soil erosion is assumed to be impeded entirely (see Section 6.1.2). The assumption that there would be virtually no soil loss from agricultural land is entirely plausible, especially under conditions of perennial crop production (e.g., alfalfa). Under these conditions the soil surface is protected from erosion (wind and/or water erosion) throughout the calendar year by the continuous vegetation cover on the ground surface. A higher biological dose to the receptor would result under these circumstances (no surface soil removal) because the radionuclides introduced into the soils by surface irrigation would not be removed by surface processes and thereby pose a greater exposure risk to a receptor via the various exposure pathways (e.g., plant uptake and subsequent human ingestion, external exposure [ground shine], etc.). An exception is the direct groundwater ingestion pathway which is independent of soil processes.

In the case of analyzing selected events of volcanic ash deposits (i.e., thin deposits of ash) onto the land resources in the Amargosa Valley, the total radionuclide quantity associated with contaminated ash deposited on the ground surface will also be "depleted" annually at a rate commensurate with the annual rate of surface soil removal. This premise is based upon the assumption of complete mixing of thin deposits of ash within the surface soil layer by plowing. Under these conditions the soil erosion rates are thereby controlled by the erosiveness of the original soil, rather than the erosion characteristics of the ash material itself or some unknown admixture of soil and ash. In this abstraction, as well as in the base case wherein the radionuclides are deposited onto the existing Amargosoa Valley soils by continuous or repetitive irrigation with contaminated water, radionuclide concentrations will be reduced annually in proportion to the annual reduction in the default 15-cm thick surface soil layer modeled by GENII-S.

5.2 LEACHING ANALYSIS

It is assumed that soil/liquid partition coefficients, K_d values, recommended for sandy textured soils are appropriate for calculating leaching coefficients for the soils in the vicinity of Lathrop Wells. The K_d values selected as input parameters for calculations of radionuclide-specific leaching coefficients are taken from Sheppard and Thibault (1990, Tables 1, 3, and A-1). These data are qualified (i.e., values were considered as "accepted data" by the YMP Office of Project Execution, OPE). The values are recommended by Sheppard and Thibault (1990, Tables 1, 3, and A-1) for sandy soils (sandy loams, loamy sands, gravelly and/or cobbly sandy loams and loamy sands) which are the types of soils found in Amargosa Valley (CRWMS M&O 1999d, Appendix C). LaPlante and Poor (1997, p. 2-22) also used these values for their calculations of leaching coefficients in a 1997 evaluation of site-specific characteristics and parameters for modeling environmental pathways of radionuclide transport in the vicinity of Yucca Mountain.

While it has been shown by some researchers (Griffin and Shimp 1976) that pH is an important factor affecting K_d, references were not found that show the effect of pH on K_d values specific for sandy soils. Griffin and Shimp (1976) looked at the effects of pH on adsorption of Pb, but this study was on pure clay minerals. Incorporated into this analysis is the range of K_d values reported by Sheppard and Thibault (1990, Tables 1, 3, and A-1). The upper range of the K_d values recommended for sandy-textured soils likely corresponds to soils with alkaline pH, similar to the soils in the Amargosa Valley. These K_d values could be different from other values used in TSPA-VA for the unsaturated zone (UZ) (CRWMS M&O 1998b, Table 7-3, p. T7-26) and saturated zone (SZ) transport calculations (CRWMS M&O 1998c, Table 8-19, pp. T8-22). However, a major reason for this difference is that, in contrast to the volcanic rock and alluvial valley fill sediments considered in the UZ/SZ transport calculations, this analysis was focused on biologically-active surface soils.

The values selected for the precipitation (*P*), irrigation (*I*), and evapotranspiration (*E*) parameters (see Table 2) are those associated with the hay and forage biosphere plant group, specifically alfalfa.

The GENII-S default value of 15 cm (Napier et al. 1988, p. 4.58) was employed as the soil depth (*D*) input parameter value. The value of 1.50 g/cm^3 was selected as the soil bulk density (ρ) because this is the computed mean value for all the soils considered in this analysis (see Table 2). It is assumed that although radionuclides can be leached below this surface soil layer, the radionuclides will not reach the underlying groundwater aquifer in the Amargosa Valley through this process. This assumption is justified because under these arid conditions, the cumulative water input (total annual precipitation and irrigation water) is not sufficient to leach constituents in the soil much beyond the designated 15 cm surface soil depth.

Volumetric water content (θ) at field capacity is not a routine analysis in standard USDA soil survey procedures and therefore these data were not available for the major soil series considered in this analysis. Field capacity water content is defined as the water content remaining in soils after complete saturation (such would occur after flood irrigation or prolonged heavy precipitation) and at the time that all free drainage as ceased (Brady 1984, p. 97). After all free drainage has occurred, the soil micropores or capillary pores remain filled with water, but water in the macropores has moved to lower depths because of gravitational forces. Napier et al. (1988, p. 4.58) used a volumetric water content estimate near field capacity for the calculation of leaching coefficients, however, his value for field capacity water content was likely equal to the soil's total porosity ($\cong$0.5) and, thus, probably calculated under the assumption that all soil pores are interstitially connected and potentially available for water occupation. However, discontinuities in pore channels exist in natural soils and generally not all pore space is filled with water at the field capacity index level. Consequently, a volumetric water content value smaller than that used by Napier et al. (1988, p. 4.58) is probably more appropriate for this analysis.

Baes and Sharp (1983, p. 20, Table 2) reported the results of an analysis of volumetric water contents at field capacity and wilting point for 154 pasture and cropland soils. The values they recommended for volumetric water content at field capacity were 0.345 ml/cm^3, 0.360 ml/cm^3, 0.319 ml/cm^3, and 0.217 ml/cm^3, for silt loams, clays/clay loams, loams, and sandy loams, respectively. Therefore, the value (0.217 ml/cm^3) recommended by Baes and Sharp (1983) is considered to be appropriate for the volumetric water retention capacity at field capacity for the soils considered in this analysis and was used as the volumetric water content *(θ)* input parameter.

6. ANALYSES/MODEL

6.1 SOIL EROSION ANALYSIS

6.1.1 Reasonable Representation Case Analyses

As discussed in Section 5.1, the USDA-established soil-loss tolerance index, *T*-value, is considered to be a sound, reasonable, and defensible representation of the maximum annual quantity of soil loss that would potentially occur in the Amargosa Valley area, now and in the future, if current institutional controls (e.g., USDA and State/County Agricultural Extension Service guidance and support for land use management) remain in place.

The annual soil depth reduction corresponding to *T*-values for each of the major soil series occurring in the vicinity of Lathrop Wells is calculated by multiplying the annual soil mass loss rate corresponding to the soil's *T*-value by the reciprocal of soil bulk density *(ρ)*

Arizo Soil – T = 11.21 t/ha/yr
ρ = 1.40 g/cm^3 or 1.40 × 10^{-6} t/cm^3

The annual soil depth reduction for this soil is:

$$11.21 \text{ t/ha/yr} \times \frac{1.0 \text{ cm}^3}{1.4 \times 10^{-6} \text{ t}} \times \frac{1 \text{ m}^2}{10{,}000 \text{ cm}^2} \times \frac{1.0 \text{ ha}}{10{,}000 \text{ m}^2} = 0.08 \text{ cm/yr}$$

The annual soil depth reduction corresponding to soil *T*-values for those soil series occurring in the vicinity of Lathrop Wells ranged from a low of 0.026 cm/yr for the Shamock series with a bulk density of 1.70 g/cm^3 to a high of 0.080 cm/yr[1] for the Arizo, Commski, Sanwell, and Yermo soils with a bulk densities of 1.40 g/cm^3 (Table 4). However, the calculated annual soil depth reduction rates are generally between 0.06 and 0.08 cm/yr, with the exception of the Shamock series, is a moderately deep, gravelly-fine sandy loam soil (CRWMS M&O 1999d, Appendix C) and is less tolerable of soil erosion than the other deeper soils before experiencing a reduction in productivity.

Table 4. Calculated Best Estimate Annual Soil Depth Reductions for the Soils in the Vicinity of Lathrop Wells, Amargosa Valley

Soil Series	*T* Value (t/ha/yr)	Bulk Density *(ρ)* (g/cm^3)		Annual Soil Depth Reduction (cm/yr)	
		Lower Range	Upper Range	Lower Bulk Density Estimate	Upper Bulk Density Estimate
Arizo	11.21	1.40	1.55	0.080	0.072
Commski	11.21	1.40	1.60	0.080	0.070
Corbilt	8.97	1.35	1.50	0.066	0.060
Sanwell	11.21	1.40	1.60	0.080	0.070
Shamock	4.48	1.50	1.70	0.030	0.026
Yermo	11.21	1.40	1.60	0.080	0.070

6.1.2 Conservative Bounding Estimate Analysis

The conservative bounding estimate analysis assumes that erosion would be eliminated altogether and thus, no annual soil depth reductions would occur for any of the above soils. The scenario (i.e., zero soil erosion losses) is considered to be conservative because these conditions would result in the maximum radiation dose to the receptor. From a realistic standpoint, the scenario is entirely plausible on those land areas under optimum management because wind and water erosion are virtually suppressed completely under conditions of perennial vegetation cover (e.g., alfalfa fields) on nearly level to level terrain such is characteristic of much of the agricultural land within the Amargosa Valley.

6.2 LEACHING ANALYSIS

The residence time of radionuclide contaminants in soils can have a large influence on the relative contribution of the various contaminant exposure pathways to a receptor's total exposure. Therefore, assessment of health risks to humans from radionuclide-contaminated soils must take into account the removal of radionuclides from the surface soil to the underlying strata by leaching. Radionuclides removed from the modeled soil layer by leaching (similarly to those depleted by surface soil removal), are no longer available for many of the possible exposure pathways including plant uptake, inhalation and ingestion of surface soil. The GENII-S code used in the TSPA for the proposed Yucca Mountain repository uses element-specific loss terms that account for removal of contamination from surface soils through leaching into deeper layers.

Equation 1 uses the relationship from Baes and Sharp (1983, p. 18) to calculate the leaching coefficients, λ (yr^{-1})

$$\lambda = \frac{P + I - E}{D \times \theta \times (1.0 + \rho / \theta \times \mathrm{K_d})} \qquad \text{(Eq. 1)}$$

where:

P , *I,* and *E* are the annual precipitation, irrigation, and evapotranspiration rates [cm/yr]

D = Depth of surface soil – default value [15 cm]

θ = Volumetric water content of soil – assumed value [0.217 ml/cm^3 or cm^3/cm^3]

ρ = Surface soil bulk density [g/cm^3]

K_d = Surface soil solid/liquid partition coefficient, K_d, for a specific radionuclide (isotope independent) and soil type [L/kg or cm^3/g]

[Note that for the volumetric water *(θ)* parameter, the units ml and cm^3 are equivalent and for the K_d parameter the units L/kg and cm^3/g are equivalent.]

The parameter with the most variability and, potentially, the largest effect on the calculated leaching coefficients is the soil solid/liquid partition coefficient (K_d). However, an extensive review of the existing soil information specific to Nye County, Nevada, and more importantly, specific to the Amargosa Valley, revealed that soil data were collected chiefly for agricultural purposes and did not include values for soil solid/liquid partition coefficients. Therefore, values recommended for sandy-textured soils by Sheppard and Thibault (1990, Tables 1, 3, and A-1) were used for the analysis because they correspond to soils with sandy loam textures which are the dominant soil textural classes found in the Amargosa Valley (CRWMS M&O 1999d, Appendix C). LaPlante and Poor (1997, p. 2-22) used the same values for their calculations of leaching coefficients in a 1997 evaluation of site-specific characteristics and parameters for modeling environmental pathways of radionuclide transport in the vicinity of Yucca Mountain.

The soils in the Amargosa Valley are alkaline (pH > 7.0) (CRWMS M&O 1999d) and some researchers have shown that pH may be an important factor affecting K_d values (Brady et al. 1998; Gee et al. 1983; Griffin and Shimp 1976; Nakayama et al. 1988; Sheppard 1985; Sheppard and Thibault 1990). However, data from studies that investigated the effect(s) of pH on K_d values for soils present in the Amargosa Valley, or even for sandy soils in general, were not successfully located. As stated previously (Section 5.2), Griffin and Shimp (1976) did evaluate the effects of pH on adsorption of Pb, but this study was on pure clay minerals. However, many of the radionuclides that would potentially be introduced into the soil through irrigation with contaminated water are metallic in nature and it is well documented that metal solubility in soils is greatly reduced with increasing pH (Bohn et al. 1979, pp. 212-213; Brady et al. 1998, p. 78; Tisdale et al. 1985, p.512; Coughtrey and Thorne 1983, Volume 2, p. 96 and p. 219). Therefore, the upper range of K_d values recommended by Sheppard and Thibault (1990) for sandy-textured soils are considered appropriate for the alkaline Amargosa Valley soils included in this analysis.

Example Calculation–Leaching Coefficient for Plutonium (Pu)

Using Equation 1, the general soil input parameter values listed in Table 2, and the soil solid/liquid partition coefficient (K_d) for Pu listed in Table 3, the leaching coefficients (λ) are calculated with the use of a FORTRAN 77 routine (MOL.19991011.0124, software routine verification documentation; MOL.19991011.0125, routine's source code listing) as follows:

Best Estimate Leaching Coefficient:

$$\lambda = \frac{10.24 + 240.44 - 235.43}{15 \times 0.217 \times (1.0 + 1.5/0.217 \times 550)} = 1.23 \times 10^{-3}$$

Conservative Bounding Estimate Leaching Coefficient:

$$\lambda = \frac{10.24 + 240.44 - 235.43}{15 \times 0.217 \times (1.0 + 1.5/0.217 \times 36000)} = 1.88 \times 10^{-5}$$

The leaching coefficients calculated for the reasonable representation case (Best Estimate) and the conservative bounding estimate (Conservative Estimate) for the 27 radionuclide elements considered in this analysis are listed in Table 5.

With the exception of molybdenum (Mo), there is a difference of either one or two orders of magnitude between the two leaching coefficient estimates for the radionuclide elements evaluated, with the Best Estimate values being greater. As mentioned previously, the conservative K_d values (Table 3) were selected to represent the conservative bounding estimate for the non-disruptive (base case) PA biosphere analysis. The resulting smaller leaching coefficients are consistent with the conservative bounding assertion because the lower the degree of radionuclide leaching from the surface soil, the greater the potential for exposure to the receptor through the radionuclide transfer pathways modeled by GENII-S. One exception is the well water consumption pathway because, as modeled in the base case performance assessment, the radionuclide content in groundwater is due entirely from the direct transfer of radionuclides in the source waste within the repository by SZ flow and transport and is therefore independent of radionuclide leaching from topsoil.

Major differences in the leaching coefficients among the various radionuclide elements are mostly due to differences in the chemical nature of the elements and their subsequent stable oxidation states. For example, the large leaching coefficient for technetium (Tc) reflects the element's propensity to exist in the +7 valence form and as the pertechnetate ion (TcO_4^-) in oxidized soil environments (Coughtrey and Thorne 1983, Vol. 3, p. 210). In this anionic form, Tc sorption by soil colloids is virtually non-existent and the radionuclide can readily be removed by leaching, much like the nitrate-nitrogen ion (NO_3^-). On the other hand, for most of the metallic elements, the calculated low leaching coefficients reflect the tendency of these elements to bind strongly onto negatively-charged soil surfaces, sometimes irreversibly (Brady et al. 1998, pp. 61-64). Additionally, many of these elements readily form carbonate mineral phases and/or become trace constituents in $CaCO_3$ precipitates under alkaline soil conditions (Brady et al. 1998, p. 47).

Table 5. Leaching Coefficients *(λ)* Calculated for 27 Radionuclide Elements (Isotope Independent). *Best Estimate* and *Conservative Estimate* Values Represent the Reasonable Representation and Conservative Bounding Estimate, Respectively

Element	Leaching Coefficient, λ, (yr^{-1})	
	Best Estimate	**Conservative Estimate**
C	1.32E-01	9.35E-02
Ni	1.69E-03	1.88E-04
Se	1.23E-02	9.66E-03
Sr	4.47E-02	3.56E-03
Y	3.98E-03	— [a]
Mo	6.68E-02	1.30E-02
Zr	1.13E-03	— [a]
Nb	4.23E-03	— [a]
Tc	2.77E+00	4.20E-02
Pd	1.23E-02	— [a]
Sn	5.20E-03	— [a]
Sb	1.50E-02	— [a]
I	5.92E-01	8.35E-03
Cs	2.42E-03	6.77E-05
Sm	2.76E-03	— [a]
Pb	2.51E-03	4.84E-04
Bi	6.76E-03	— [a]
Po	4.51E-03	9.65E-05
Ra	1.35E-03	3.23E-05
Ac	1.50E-03	— [a]
Th	2.12E-04	4.52E-06
Pa	1.23E-03	— [a]
U	1.93E-02	3.08E-04
Np	1.32E-01	1.74E-03
Pu	1.23E-03	1.88E-05
Am	3.56E-04	2.26E-06
Cm	1.69E-04	2.94E-05

NOTE: [a] Conservative Estimate was not calculated because an applicable K_d value was not provided by Sheppard and Thibault (1990, Tables 1, 3, and A-1). Although zero could be used as the conservative value, this might be unreasonably conservative and unrealistic in many cases (e.g., elements with high leaching coefficients). Therefore it is recommended that the best estimate be used as the conservative value for those radionuclide elements that do not have a Conservative Estimate listed in Column 3 above.

6.3 EXPECTED SOURCES OF UNCERTAINTY AND APPLICATION TO PA ANALYSIS

Because the analyses of annual soil depth reduction rates were deterministic in nature, i.e., based upon reasonable maximum soil erosion rates associated with current land use practices, the major source of uncertainty in the analysis is the assumption that these current management and conservation practices will continue into the future. Land resources in the Amargosa Valley could be used and managed in a variety of ways. However, as discussed previously (Section 5.1), technical guidance and assistance is currently provided to land owners/managers through local USDA-sponsored Conservation Districts with the objective of fostering land use practices that will result in sustained productivity. Maintaining annual soil erosion losses below the levels prescribed by the established soil loss tolerance factor (*T*-value) is a major focus of this program. If current institutional services such as the Southern Nye County Conservation District guidance and assistance to land owners/managers in the Amargosa Valley are abandoned, present land use practices could deviate to other less conservation-oriented uses. For example, some of the land currently used for alfalfa production could be taken out of agricultural production and used for other purposes such as urban development. Under these circumstances, and especially during the transitional periods when the land has been graded for development but the development has not occurred, annual soil losses exceeding the USDA established *T*-value levels could occur.

Another potential source of uncertainty in the soil depth reduction calculations is related to uncertainty in actual soil bulk density values in the area in which the critical group would reside. For the soil series evaluated, a range between an upper and lower bulk density bounding value were provided (Table 1). Calculated annual depth reduction rates between the upper and lower bulk density values provided for each soil series differed only between 10 to 13 percent (Table 4). Compared to the potential effects of the uncertainty associated with the changes in annual erosion rates that could potentially result from land use or management changes, uncertainty in the calculations arising from soil bulk density variation within soil series is relatively minor.

The largest degree of uncertainty in the leaching coefficient calculations is associated with the K_d values selected for each radionuclide, hence the leaching coefficient calculations are most sensitive to these input parameters (exceptions may occur when the element K_d is small (≤ 1)). Published information on radionuclide-specific K_d measurements for soils in the Amargosa Valley was not found, and, potentially, there is a degree of uncertainty in how the values used in the calculations in Table 3 would differ from values obtained from actual experimental analysis on the six Amargosa Valley soil series considered in the analysis.

7. SUMMARY AND CONCLUSIONS

The analyses reported in this AMR were conducted to address the potential impact(s) of erosion and leaching as they relate to the accumulation/removal of radionuclides in soils. The results of this study will be used in subsequent AMR analyses to determine the total annual build-up of radionuclides resulting from irrigation with contaminated groundwater and the potential removal rate of radionuclides in contaminated ash deposits within the Amargosa Valley. To assess radionuclide build-up in soils subjected to continuous or repetitive irrigation with contaminated water, an estimate of concurrent soil loss by erosion is needed. Although the GENII-S code used in the TSPA biosphere analysis considers the leaching process in its calculations, the objective of this analysis of soil/liquid partition coefficients was to derive values that are more appropriate for the soil environment in the Amargosa Valley.

The estimates of annual soil depth reduction (Table 4) are applicable for use in calculations of net cumulative radionuclide build-up as a result of irrigation on arable land with contaminated groundwater, as well as for assessing the removal of radionuclide-contaminated ash deposited on these lands. In the former case, the radionuclide content removed annually by surface soil erosion will be subtracted from the annual irrigation input of radionuclides. In the latter case, the total radionuclide quantity associated with contaminated ash deposited on the ground surface will be "depleted" annually at a rate commensurate with the annual rate of surface soil removal. This second scenario is based on the assumption that thin deposits of ash within the surface soil layer are completely mixed within the original surface soil layer, with subsequent erosion rates controlled by the erosion characteristics of the original soil, rather than the erosion characteristics of the ash material itself or some unknown admixture of soil and ash. The radionuclide concentrations in the soils will be reduced in proportion to the annual soil depth reduction estimates (Table 4) from the default 15-cm thick surface soil layer modeled by GENII-S for both of the above abstractions.

Two values were calculated for the surface soil erosion loss estimates and the leaching coefficients: 1) a reasonable estimate based on the soil properties in the Amargosa Valley and the land use characteristics of the critical group proposed by the NRC, and 2) a conservative, high dose-yielding bounding value calculated under the conditions that, potentially, would result in higher exposure rates (i.e., the conservative bounding estimate).

The USDA-established soil loss tolerance value *(T*)*,* designated as the upper limit of annual surface soil loss beyond which long-term productivity is compromised, was selected as the reasonable and defensible maximum annual quantity of soil removal by erosion that, potentially, would occur in the Amargosa Valley area. This is based upon the assumption that the current USDA and State/County Agricultural Extension Service guidance and support for land use management remain in place.

The annual soil depth reduction estimates (Table 4) for the soils occurring in the vicinity of Lathrop Wells ranged from a low of 0.026 cm/yr for the Shamock series with a bulk density of 1.70 g/cm^3 to a high of 0.080 cm/yr for the Arizo, Commski, Sanwell, and Yermo soils with bulk densities of 1.40 g/cm^3. However, with the exception of the Shamock series, which is a moderately deep, gravelly fine sandy loam soil and therefore less resilient to soil erosion before experiencing a reduction in productivity, the calculated annual soil depth reduction rates are generally between 0.06 and 0.08 cm/yr. For the conservative bounding estimate, soil erosion was assumed to be checked entirely (i.e., no surface soil erosion loss).

The leaching coefficient calculations are most sensitive to the K_d input parameter, with the magnitude of the leaching coefficients being inversely related to the magnitude of element's respective K_d. A major objective of the analysis was to attempt to use site-specific soil data, including K_d values, preferably obtained from studies on soils present in the vicinity of Yucca Mountain. However, in the absence of such data, values recommended for sandy-textured soils by Sheppard and Thibault (1990, Tables 1, 3, and A-1) were chosen for the analysis. These values are deemed to be the most appropriate and comprehensive data available. Other input parameter values including soil bulk density, precipitation, evaporation, and irrigation rate, were based upon data obtained from the Amargosa Valley.

The leaching coefficients (Table 5) calculated with the best estimate soil/liquid partition coefficient (K_d) were generally larger, by either one or two orders of magnitude, than those calculated with the conservative K_d estimates. Differences in the leaching coefficients among the various radionuclide elements were largely due to differences in their chemical nature and their subsequent stable oxidation states. For most of the metallic and metallic-like elements (e.g., Am, Ni, Sm. Pu, U), low leaching coefficients were attributed to strong binding by negatively-charged soil surfaces (i.e., high K_d). On the other hand, the large leaching coefficient calculated for Tc resulted from the element's low K_d, reflecting the element's propensity to exist as an anion in aerobic soils, and thus exhibit low adsorption to negatively charged mineral colloids in oxidized soil environments.

It is interesting to note that those elements that are most likely to reach the accessible environment, (where exposure occurs), via the groundwater pathway, are also the most rapidly leached from the (agricultural) soil and are consequently less available for crop/animal uptake and subsequent consumption by humans. This is important because Tc and I, which both have relatively small K_d values are, from the standpoint of migration from the repository to the biosphere, two of the largest potential dose contributors in the 10,000 year regulatory time frame. Consequently, uncertainty in the K_d values (for the soils in Amargosa Valley) of these two elements could significantly impact dose calculations and perhaps the margin of regulatory compliance.

For the conservative bounding estimate, the use of the largest K_d value recommended for each radionuclide element by Sheppard and Thibault (1990, Tables 1, 3, and A-1) generally produced a considerably smaller leaching factor, particularly where the maximal (conservative estimate) K_d was substantially much larger than the "best estimate" K_d. For exposure through the food chain pathways (via soil), the potential dose from metallic elements such as neptunium (Np), plutonium (Pu), and others is increased, perhaps significantly, because of their retention in the surface soil. Of course, since the resulting soil concentrations of these elements are relatively greater for this case, the dose risk due to direct external (ground shine) and inhalation exposure pathways will be increased. However, the TSPA-VA performance assessment (CRWMS M&O, 1998a) showed that ground shine and inhalation contribute a very small fraction of the total dose due to all pathways.

The TSPA-VA analyses did not consider soil build-up, but this process is included in the TSPA-SR. Thus, the conservative bounding estimate analyses conducted for this AMR will make the PA analysis more comprehensive because they are a necessary component of the soil buildup abstraction.

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8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

MO9903CLIMATOL.001. Climatological Tables From 1986-1997 Meteorological Data From Site 1 Through Site 9 EFPD Meteorological Sites. Submittal date: 03/23/1999.

MO9912MWDEEA06.003. Evapotranspiration Estimates for Alfalfa in the Reference Biosphere. Submittal date: 12/14/1999.

MO9912SPAING06.033. Ingestion Exposure Pathway Parameters. Submittal date: 12/22/1999.

SN9912USDASOIL.000. U.S. Department of Agriculture (USDA) Soil Survey Data – Lathrop Wells. Submittal date: 12/20/99.

SN0002KDVALUES.000 Soil/Liquid Partition Coefficients, K_d values. Submittal Date: 02/10/00.

ATTACHMENT I – DOCUMENT INPUT REFERENCE SYSTEM (DIRS)

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.:	Change:	Title:
ANL-NBS-MD-000009 REV 00		Evaluate Soil/Radionuclide Removal by Erosion and Leaching

Input Document							8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
2a 1	Baes, C.F., III and Sharp, R.D. 1983. "A Proposal for Estimation of Soil Leaching and Leaching Constants for Use in Assessment Models." *Journal of Environmental Quality, 12* (1), 17-28. Madison, Wisconsin: Published Cooperatively by American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. TIC: 245676.	Page 18 Table 2, p. 20	N/A; Reference Only	5.2, 6.2	Equation for calculating leaching coefficients. Assumed estimate of volumetric water content parameter used in leaching coefficient equation.	N/A	N/A	N/A	N/A
2	Bohn, H.L.; McNeal B.L.; and O'Connor, G.A. 1979. *Soil Chemistry.* New York, New York: John Wiley & Sons. TIC: 245713.	Pages 212-213	N/A; Reference Only	6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
3	Brady, N.C. 1984. *The Nature and Property of Soils*. 9th Edition. New York, New York: Macmillan Publishing Co. Library tracking number: 238332C.	Page 434 Page 97	N/A; Reference Only	4.1.1 5.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
4	Brady, P.V.; Brady, M.V; and Borns, D.J. 1998. *Natural Attenuation: CERCLA, RBCA's, and the Future of Environmental Remediation*. Boca Raton, Florida: Lewis Publishers. TIC: 245714	Pages 47, 61-64, 78	N/A; Reference Only	6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
5	Coughtrey, P.J. and Thorne, M.C. 1983. *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems – A Critical Review of Data*. EUR 8115. Rotterdam, The Netherlands: A.A. Balkema. TIC: 240299.	Volume 2 pages 96, 219; Volume 3 page 210	N/A; Reference Only	6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
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1. Document Identifier No./Rev.: ANL-NBS-MD-000009 REV 00	Change:	Title: Evaluate Soil/Radionuclide Removal by Erosion and Leaching

Input Document							8. TBV Due To			
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
6	CRWMS M&O. 1998. *Total System Performance Assessment–Viability Assessment (TSPA-VA) Analyses Technical Basis Document. Chapter 9 Biosphere.* B00000000-01717-4301-00009, Rev 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0009.	All	N/A; Reference Only	1 7	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
7	CRWMS M&O. 1998. *Total System Performance Assessment–Viability Assessment (TSPA-VA) Analyses Technical Basis Document. Chapter 7 Unsaturated Zone Radionuclide Transport*. B00000000-01717-4301-00007 Rev 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0007.	Table 7-3	N/A; Reference Only	5.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
8	CRWMS M&O. 1998. *Total System Performance Assessment–Viability Assessment (TSPA-VA) Analyses Technical Basis Document. Chapter 8 Saturated Zone Flow and Transport*. B00000000-01717-4301-00008 Rev 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0008.	Table 8-19	N/A; Reference Only	5.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
9	CRWMS M&O. 1999. *Status of the Radionuclide Screening for the TSPA-SR*. Input Transmittal R&E-PA-99217.Ta. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990719.0182.	All	N/A; Reference Only	1	Reference of other project analysis used as basis for selection of radionuclide elements to included in the leaching coefficient calculations.	N/A	N/A	N/A	N/A
10	CRWMS M&O. 1999c. *Conduct of Performance Assessment.* Activity Evaluation. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991028.0092.	All	N/A; Reference Only	2.0	General reference to activity evaluation.	N/A	N/A	N/A	N/A

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
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1. Document Identifier No./Rev.:	Change:	Title:
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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
11	CRWMS M&O. 1999. *Evaluate Soil/Radionuclide Removal by Erosion and Leaching Rev. 00*. TDP-NBS-MD-000006. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991209.0197.	All	N/A; Reference Only	1	Development Plan describing work to be conducted under this AMR analysis.	N/A	N/A	N/A	N/A
12	CRWMS M&O. 1999. *Evaluation of Soils in the Northern Amargosa Valley*. B00000000-01717-5705-00084 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990224.0268.	Figure 1 pages 2-3 Appendix C	N/A; Reference Only	4.1.1, 6.1.1 4.1.2, 5.2, 6.2	Soil survey information describing the soils to be considered in the analysis. Appendix C – soil series descriptions.	N/A	N/A	N/A	N/A
13	DOE (U.S. Department of Energy) 2000. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 9. Washington D.C.: DOE OCRWM. ACC: MOL.19991028.0012.	All	N/A; Reference Only	2.0	Reference to Quality Assurance Requirements and Description	N/A	N/A	N/A	N/A
14	Dyer, J. R. 1999. "Revised Interim Guidance Pending Issuance of New U. S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from J. R. Dyer (DOE) to D. R. Wilkins (CRWMS M&O), September 9, 1999, OL&RC:SB-1714, with enclosure, "Interim Guidance Pending Issuance of New U. S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01)". ACC: MOL.19990910.0079.	All	N/A; Mgmt Edict/TDL	1.0 4.2	General reference to provide guidance on use of proposed rule 10 CFR Part 63.	N/A	N/A	N/A	N/A
15	Gee, G.W.; Rai, D.; and Serne, R.J. 1983. "Mobility of Radionuclides in Soil." *Chemical Mobility and Reactivity in Soil Systems*. *SSSA Special Publication Number 11*, 203-227. Madison, Wisconsin: Soil Science Society of America: American Society of Agronomy. TIC: 229832. Copyright Granted	All	N/A; Reference Only	6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A

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1. Document Identifier No./Rev.:	Change:	Title:
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	Input Document						8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
16	Golder. 1998. *RIP Integrated Probabilistic Simulator for Environmental Systems. Theory Manual and User's Guide*. November 1998. Redmond, Washington: Golder Associates Inc. TIC: 238560.	All	N/A; Reference Only	1	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
17	Griffin, R.A. and Shimp, N.F. 1976. "Effect of pH on Exchange-Adsorption or Precipitation of Lead from Landfill Leachates by Clay Minerals." *Environmental Science and Technology, 10* (13), 1256-1261. Washington, D.C.: American Chemical Society. TIC: 246051. Copyright Granted	All	N/A; Reference Only	5.2, 6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
18	LaPlante, P.A. and Poor, K. 1997. *Information and Analyses to Support Selection of Critical Groups and Reference Biospheres for Yucca Mountain Exposure Scenarios.* CNWRA 97-009. San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. TIC: 236454.	Page 2-22	N/A; Reference Only	5.2, 6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
19	Leigh, C.D.; Thompson, B.M.; Campbell, J.E.; Longsine, D.E.; Kennedy, R.A.; and Napier, B.A. 1993. *User's Guide for GENII-S: A Code for Statistical and Deterministic Simulations of Radiation Doses to Humans from Radionuclides in the Environment*. SAND91-0561. Albuquerque, New Mexico: Sandia National Laboratories. TIC: 231133.	All	N/A; Reference Only	1	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.:	Change:	Title:
ANL-NBS-MD-000009 REV 00		Evaluate Soil/Radionuclide Removal by Erosion and Leaching

	Input Document						8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
20	MO9903CLIMATOL.001. Climatological Tables From 1986-1997 Meterological Data From Site 1 Through Site 9 EFPD Meteorolgical Sites. Submittal date: 03/23/1999.	All	N/A; Qualified-VL2	4.1.2	Annual precipitation value for Lathrop Wells	N/A	N/A	N/A	N/A
21	MO9912MWDEEA06.003. Evapotranspiration Estimates for Alfalfa in the Reference Biosphere. Submittal date: 12/14/1999.	All	N/A; Technical Product Output	4.1.2	Annual evapotranspiration rate value for alfalfa production in Amargosa Valley	1	X	N/A	N/A
22	MO9912SPAING06.033. Ingestion Exposure Pathway Parameters. Submittal date: 12/22/1999.	All	TBV-3958	4.1.2	Irrigation rate for alfalfa production in Amargosa Valley	1	X	N/A	N/A
23	McCurley, R. 1999. Documentation of SOILMODEL program to calculate leaching factors Memo ACC: MOL.19991011.0125.	All	N/A, Reference Only	3.0	Description of SOILMODEL program (FORTRAN 77) that calculates radionuclide-specific leaching coefficients	N/A	N/A	N/A	N/A
24	McCurley, R. 1999. SOIL MODEL version A1.20 Software Routine Verification, Documentation of SOIL MODEL Program to Calculate Leaching Factors Memo ACC: MOL.19991011.0124.	All	N/A, Reference Only	3.0	Software routine verification documentation for calculation of leaching coefficients	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
25	Nakayama, S.; Arimoto, H.; Yamada, N.; Moriyama, H.; and Higashi, K. 1988. "Column Experiments on Migration Behaviour of Neptunium(V)." *Radiochimica Acta,44/45,* 179-182. Munich: R. Oldenbourg Verlag; New York, New York: Academic Press. TIC: 246055.	All	N/A; Reference Only	6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
26	Napier, B.A.; Peloquin, R.A.; Strenge, D.L.; and Ramsdell, J.V. 1988. *Conceptual Representation. Volume 1 of GENII: The Hanford Environmental Radiation Dosimetry Software System.* PNL-6584. Richland, Washington: Pacific Northwest Laboratory. TIC:206898.	Page 4.58	N/A; Reference Only	5.2	In section 5.2, general reference to provide background and scientific information to report and the default soil depth parameter (D).	N/A	N/A	N/A	N/A
27	NRC (U.S. Nuclear Regulatory Commission). 1998. *Issue Resolution Status Report Key Technical Issue: Total System Performance Assessment and Integration.* Revision 1. Washington, D.C.: Division of Waste Management, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission. ACC: MOL.19990105.0083.	All	N/A; Reference Only	4.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
28	SN0002KDVALUES.000. Soil Solid/Liquid Partition Coeficients, Kd Values. Submittal Date: 02/10/00. URN-0010	Tables 1, 3, and A-1, values for sandy soils.	N/A; Accepted Data – AMOPE Approved	4.1.2	Soil solid/liquid partition coefficients, K_d values for Amargosa Valley Soils	N/A	N/A	N/A	N/A
29	SN9912USDASOIL.000. U.S. Department of Agriculture (USDA) Soil Survey Data – Lathrop Wells. Submittal date: 12/20/99.	Soil Loss Tolerance Values, Soil Bulk Density Values	N/A; Accepted Data – AMOPE Approved	4.1.1 4.1.2	Data source – input parameter values used for calculating annual soil loss estimates.	N/A	N/A	N/A	N/A

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
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1. Document Identifier No./Rev.: ANL-NBS-MD-000009 REV 00	Change:	Title: Evaluate Soil/Radionuclide Removal by Erosion and Leaching

	Input Document		4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
30	Sheppard, M. I. 1985. "Radionuclide Partitioning Coefficients in Soils and Plants and Their Correlation." *Health Physics, 49,* (1), 106-111. Baltimore, Maryland: Lippincott Williams & Wilkins. TIC: 246136.	All	N/A , Reference Only	6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
31	Sheppard, M.I. and Thibault, D.H. 1990. "Default Soil Solid/Liquid Partition Coefficients, K_ds, for Four Major Soil Types: A Compendium." *Health Physics, 59* (4), 471-482. New York, New York: Pergamon Press. TIC: 245952	Tables 1, 3, and A-1	N/A; Reference Only	4.1.2 5.2 6.2 7	General reference to recommended soil/liquid partition coefficients (Kd values) for use in leaching coefficient calculations.	N/A	N/A	N/A	N/A
32	Tisdale, S.L.; Nelson, W.L.; and Beaton, J.D. 1985. *Soil Fertility and Fertilizers. 4th Edition.* New York, New York: Macmillan Publishing Co. TIC: 240775.	Pages 4-6, 147-150, 512, 634	N/A; Reference Only	6.2	General reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
33	Troeh, F.R.; Hobbs, J.A.; and Donahue, R.L. 1980*. Soil and Water Conservation for Productivity and Environmental Protection*. Englewood Cliffs, New Jersey: Prentice-Hall. TIC: 246612.	Page 149 Pages 4-6, 147-150	N/A; Reference Only	4.1.1 5.1	General Reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
34	USDA (U.S. Department of Agriculture) Natural Resource Conservation Service. 1998. *Achieving Effective Land Stewardship: A Framework for Action.* Washington, D.C.: U.S. Department of Agriculture. TIC: 246168.	All	N/A; Reference Only	5.1	General Reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
35	Wischmeier, W.H. and Smith, D.D. 1978. *Predicting Rainfall Erosion Losses—A Guide to Conservation Planning, Agriculture Handbook Number 537,* 58 pp. Washington, D.C.: Department of Agriculture, Science and Education Administration. TIC: 245752.	All	N/A; Reference Only	5.1	General Reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A

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	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
36	Woodruff, N.P. and Siddoway, F.H. 1965. "A Wind Erosion Equation." *Soil Science Society of America Proceedings, 29* (5), 602-608. Madison, Wisconsin: Soil Science Society of America. TIC: 246058.	All	N/A; Reference Only	5.1	General Reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
37	Yoder, D. and Lown, J. 1995. "The Future of RUSLE: Inside the New Revised Universal Soil Loss Equation." *Journal of Soil and Water Conservation, 50* (5), 484-489. Ankeny, Iowa: Soil Conservation Society of America. TIC: 246069.	All	N/A; Reference Only	5.1	General Reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
38	*Soil Conservation and Domestic Allotment Act of 1935*. (Public Law 74-46, 49 Stat. 163).	Chapter 85	N/A; Reference Only	5.1	General Reference to provide background and scientific information to report.	N/A	N/A	N/A	N/A
38	64 FR 8640. Disposal of High Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain. TIC: 242725. Readily Available.	All	N/A, Reference Only	1.0	Regulatory document describing critical group characteristics	N/A	N/A	N/A	N/A
40	AP-SI.1Q, Rev. 2, ICN 1. *Software Management.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19991101.0212.	Section 5.1	N/A, Reference Only	3.0	General reference to a project quality assurance procedure.	N/A	N/A	N/A	N/A
41	AP-SIII.3Q, Rev. 0, ICN 1. *Submittal and Incorporation of Data to the Technical Data Management System.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19990831.0078.	All	N/A, Reference Only	2.0	General reference to a project quality assurance procedure.	N/A	N/A	N/A	N/A

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.: ANL-NBS-MD-000009 REV 00	Change:	Title: Evaluate Soil/Radionuclide Removal by Erosion and Leaching

Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
42	AP-3.10Q, Rev. 1, ICN 0. *Analyses and Models.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19990702.0314.	All	N/A, Reference Only	2.0	General reference to a project quality assurance procedure.	N/A	N/A	N/A	N/A
43	NLP-2-0, Rev. 5. *Determination of Importance Evaluations.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981116.0120.	All	N/A, Reference Only	2.0	General reference to a project quality assurance procedure.	N/A	N/A	N/A	N/A
44	QAP-2-0, Rev. 5. *Conduct of Activities* . Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980826.0209.	All	N/A; Reference Only	2.0	Provided guidance for producing quality affecting work	N/A	N/A	N/A	N/A
45	QAP-2-3, Rev. 10. *Classification of Permanent Items.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990316.0006.	All	N/A, Reference Only	2.0	Quality assurance guidance	N/A	N/A	N/A	N/A

ATTACHMENT II – SOFTWARE ROUTINE VERIFICATION DOCUMENTATION AND CODE LISTING

RMS SL # 506330

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation
Albuquerque, New Mexico 87185-0778

WBS: 1.2.3
~~QA:~~ QA: QA 8/26/99

date: August 12, 1999

to: Mario Chavez, 6850/JHA
SNL YMP Software Configuration Management Coordinator

from: Ron McCurley, 6851/NMERI

subject: SOIL_MODEL Version A1.20 Software Routine Verification (Documentation of eng. Soil Model Program to Calculate Leaching Factors) 8/26/99
Calculation of Leaching Factors (Richard Aguilar & Ron McCurley, SNL-PAO)
AMR - B0050 "Evaluate Soil/Radionuclide Removal by Erosion & Leaching - ANL-NBS-MD-000009.

A software routine (consisting of several modules) was developed in accordance with AP-SI.1Q for the purpose of calculating leaching factors to be used by GENII-S in the development of BDCF's. The software developed, SOIL_MODEL, version A1.20, is in FORTRAN 77. The source code and executable reside in the following directory location on a DEC ALPHA at Sandia National Laboratories:

I1:[000000.RDMCCUR.INEEL_PA98.YMP_99.BIOSPHERE.SOIL_MODEL.SOURCE_COD E].

The equation used to determine the calculated leaching factors ($\lambda_{s,k}$) adapted from Baes and Sharp (1983) is:

$$\lambda_{s,k} \quad = \quad (P + I - E) / [D_s * \theta_s * (1.0 + \rho_s/\theta_s * K_{ds,k})] \quad \text{where}$$

P , I, and E are the annual precipitation, irrigation, and evapotranspiration rates [cm/yr]
D_s = Depth of surface soil [m]
θ_s = Volumetric water content of soil [ml/cc]
ρ_s = Surface soil bulk density [g/cc]
$K_{ds,k}$ = Surface soil solid/liquid partition coefficient, K_d, for nuclide "k" (isotope independent) and soil type "s"

For this calculation, the parameters on the right side of the equation have been assigned (*see* attached table for K_d values) the following values:

Soil bulk density (ρ_s) = 1.5 g/cm^3

Soil (topsoil) depth (D_s) = 15.0 cm

Volumetric soil water content (θ_s) = 0.217 ml/cm^3

Natural precipitation (P) = 3.51 in/yr (8.91 cm/yr)

Irrigation rate (I) = 86.99 in/yr (220.95 cm/yr)

Evapotranspiration (E) = 84.50 in/yr (214.63 cm/yr)

(i.e., $P + I - E = 15.23$ cm/yr)

Documentation of input

P, I, and E values were obtained from ANL-MGR-MD-000001, Rev. 00A *- Input Parameter Values for External and Inhalation Radiation Exposure Analysis.* P.E. Lederle – Originator; Draft, August 1999.

The K_ds values are from one source: Sheppard & Thibault (1990), for sandy soils
Baes and Sharp (1983) and LaPlante & Poor (1997) also recommend the use of the K_ds reported in Sheppard.

Volumetric water content we used (0.217 ml/ cm^3) was that value that corresponds to field capacity (1/3 bar) for sandy loam soils (Baes and Sharp, 1983).

Bulk densities (ρ_s) in the range of 1.50 g/cm^3 are typical for the sandy soils that exist in Armagosa Valley.

The depth of surface soil (D_s) is reasonable for agricultural soils.

Results:

Below are selected radionuclides with corresponding input K_ds in the second column, the calculated (by SOIL_MODEL) leaching coefficients and the values as calculated using a HP 32S (Hewlett Packard) calculator with input values as specified above substituted in the leaching equation, also as specified above.

Radionuclide	K_d	Leaching coefficient SOIL_MODEL (3 significant digits)	calculator (4 significant digits)
TC99	1.00E-01	2.77E+00	2.767E+00
I129	1.00E+00	5.92E-01	5.913E-01
PU242	5.50E+02	1.23E-03	1.230E-03

The table above shows a verification of the calculation of leaching coefficients over a range of K_ds by the code SOIL_MODEL.

Literature Cited:

Baes C. F., III and R. D. Sharp. 1983. A proposal for estimation of soil leaching constants for use in assessment models. *J. Environ. Qual.* 12:17-28.

LaPlante, P. A. and K. Poor. 1997. *Information and Analyses to Support Selection of Critical Groups and Reference Biospheres for Yucca Mountain Exposure Scenarios.* CNWRA 97-009. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

P.E. Lederle – Originator. 1999. ANL-MGR-MD-000001, Rev. 00A - *Input Parameter Values for External and Inhalation Radiation Exposure Analysis.* (Draft Document – in checking)

NRC [Nuclear Regulatory Commission]. 1995. *NRC Iterative Performance Assessment Phase 2: Development of Capabilities for Review of a Performance Assessment for a High-Level Waste Repository.* R. G. Wescott, M. P. Lee, T. J. McCartin, N. A. Eisenberg, R. G. Baca. Eds. NUREG-1464. Washington, DC: Nuclear Regulatory Commission.

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YMP:1.2.1.12:SFT:Q:SOIL_Model Version A1.20, Software Routine Verification

QA:QA

Documentation of SoilModel Program to Calculate Leaching Factors

Hard Copy Listing of Source Code for Soil Model Routine 8/12/99

emj 8/26/99

MOL.19991011.0125

```
soil.for;3

      PROGRAM SOILMODEL
C*********************************************************************
C
C                              SOILMODEL
C                              ------
C
C       The SOILMODEL program calculates changes in radionuclide
C       distributions in the surface soil due to leaching, erosion
C
C                              JULY 1999
C
C
C                               Authors
C                               -------
C
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C
C
C                              Abstract
C                              --------
C
C  Translates input parameters used in (1) the leaching equation from
C  Baes & Sharp to a leaching rate, (2) the USLE (Universal Soil Loss
C  Equation) to an surface soil removal rate due to water erosion.
C
C                          Primary Reference
C                          -----------------
C                          Baes & Sharp 1983
C
C
C
C                           Update History
C                           --------------
C
C
C Version           Date          Modified by          Changes
C
C DEC ALPHA A1.00   June,1999     Ron D. McCurley      Original version
C DEC ALPHA A1.20   July 2,1999   Ron D. McCurley      Added additional
C                                                      radionuclides
C DEC ALPHA A1.22   Aug 6,1999    Ron D. McCurley      Added additional
C                                                      radionuclide Mo93,
C                                                      fix for English units (inche
s)
C
C                             Disclaimer
C                             ----------
C
C       This computer program was prepared as an account of work
C sponsored by an agency of the United States Government.  Neither the
C United States Government nor any agency thereof, nor any of their
C employees, nor any of their contractors, subcontractors,or their
C employees, makes any warranty, express or implied, or assumes any
C legal liability or responsibility for the accuracy, completeness,
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C endorsement, recommendation, or favoring by the United States
C Government, any agency thereof or any of their contractors or
C subcontractors.  The views and opinions expressed herein do not
C necessarily state or reflect those of the United States
C Government, any agency thereof or any of their contractors
C or subcontractors.
C
```

```
C
C                              Program Modules
C                              ---------------
C
C    EXDATE:    Returns the current date in a character string.
C    EXTIME:    Returns the current time in a character string.
C    EXCPUS:    Returns accumulated CPU time, in seconds.
C    EXPARM:    Returns the operating environment parameters.
C    FFRDLRDS:  Substitute for subroutine FREFLD, input is prompted for, read,
C               and echoed, using specified I/O units.
C    SOILMODEL: SOILMODEL program main driver.
C    PREPRO:    SOILMODEL input preprocessor which performs QA functions and calls
C               routine for parsing command line arguements consisting of
C               filenames.  Those files are opened when appropriate or prompted
C               for if not supplied on the command line or set to defaults.
C    PROCTL:    Processes SOILMODEL input control file, and determines new
C               parameters needed for INFIL control file.
C    QAABORT:   Prints a fatal error message and then aborts job in case of error
C               detected in input.
C    QABANNER:  Prints the program banner to the terminal or an output file.
C               The banner includes the program name in large letters, the program
C               description, the version, the revision date, the author, the
C               sponsor, and the current run date and time.
C    QADOEDIS:  Prints the Sandia DOE contract statement and the DOE disclaimer
C               to the terminal or an output file.
C    QAFETCH:   Returns the program QA information.  Routine QASETUP must be
C               called to set up the CAMCON_LIB common before QAFETCH is called.
C    QAPAGE:    Starts a new page (except for the first call) and puts the QA
C               information (program name, run time, etc.) at the top of each
C               page.  At the end of the file, it prints the ending QA
C               information.
C    QAMAXERR:  Checksan integer value against a maximum value.  If the value is
C               over the maximum, an error message is printed and QAABORT is
C               called (if requested).
C    QASETUP:   Called at the start of the program.  It performs initialization
C               details common to all programs.  Specifically, it:
C                 Initializes the CPU time,
C                 Sets the common area CAMCON_LIB common with the passed
C                 information,
C                 Sets the current run date and time,
C                 Sets the execution machine and operating system,
C                 Adds the machine to the program version,
C                 Starts a new page on the terminal.
C    RDPAR:     Reads the SOILMODEL input control file parameter information
C               and returns the variables found.
C    TYPRQS:    Outputs a request for a character string and then inputs the
C               character string in an interactive session.
C    WELCOM:    Produces Instructions for main program usage, writes banner and
C               program credits.
C
C                            Subroutine Flowchart
C                            --------------------
C
C    SOILMODEL-+-QASETUP-+-EXCPUS
C              |         |
C              |         +-EXPARM
C              |         |
C              |         +-STRPACK
C              |         |
C              |         +-EXDATE
C              |         |
C              |         +-EXTIME
C              |
C              +-QAFETCH
C              |
C              +-PREPRO-+-EXPARM
C              |        |
C              |        +-RDCMDL
C              |        |
C              |        +-WELCOM--QABANNER
```

```
C               |        |
C               |        +-TYPRQS
C               |        |
C               |        +-QABANNER
C               |        |
C               |        +-QAPAGE
C               |        |
C               |        +-QADOEDIS
C               |
C               +-PROCTL-+-RDPAR--+-FFRDLRDS
C               |        |        |
C               |        |        +-QAABORT
C               |        |
C               +-LEACH--+-GETKD
C               |
C               +-EXCPUS
C               |
C               +-QAPAGE
C
C
C                              Assumptions and Limitations
C                              ---------------------------
C
C     Language used is ANSI X3.9-1978 FORTRAN 77 except that comments
C     and Hollerith strings use lowercase characters. INTEGER and REAL
C     variable names are explicitly typed.  Machine dependent coding
C     exists in subroutine WRI
C
C                                        Statistics
C                                        ----------
C
C        ALPHA  Version 2.02:
C        12659 lines total,    6730 FORTRAN lines,    5508 FORTRAN statements
C         5930 comment lines, 3487 text lines,
C        total/FORTRAN lines ratio: 1.881
C
C                                    Types of data sets
C                                    ------------------
C
C   INPUT/
C     ASCII:  in units INASCI, KDLIB
C
C   OUTPUT/
C     ASCII:  in units IOUT, NOUTFL
C
C                                       Files used
C                                       ----------
C
C   filename              unit     description
C   SYS$COMMAND             5        Terminal screen/keyboard
C  (SOILMODEL_SXX.DBG)    6 or 7   (OPTIONAL) SOILMODEL diagnostics/debug file
C  (SOILMODEL_SXX.INP)      8        SOILMODEL input control file
C  (SOILMODEL_SXX.OUT)      9        SOILMODEL output file generated by SOILMODEL
C
C***********************************************************************
C234567
      IMPLICIT NONE
      INCLUDE 'IOCOM.INC/LIST'
      INCLUDE 'PARAMS.INC/LIST'
      INCLUDE 'CAMCON_COMMON.INC/LIST'

      INTEGER  IERR, MORMEMC, MORMEMR, NUMNUC
      REAL RDUM
      REAL ALAMLCH(MAXNUC)

      CHARACTER*12 INPROG
      CHARACTER*8  INVERS, INDATE
      CHARACTER*8  NAMNUC(MAXNUC)
      CHARACTER*80 INAUTH, INSPON
      CHARACTER*80 FOUT, FDBG, FLIB, FUSR
```

```
      LOGICAL  WRTOUT

      EXTERNAL BLOCK

C<><><><><><><><><><><><>
C...Begin Procedures...
C<><><><><><><><><><><><>

C     ...Perform routine initializations
      CALL QASETUP ( PROGRM, PVERSN, PDATE, AUTHOR, SPONSR )
C
C     ...Call for program QA information
      CALL QAFETCH (PROGRM, PVERSN, PDATE, RUNDAT, RUNTIM,
     &              AUTHOR, SPONSR)
C
C     ...Prompt USER for program execution control options
      CALL PREPRO( FUSR, FLIB, FOUT, FDBG )

C
C**** Process the SOILMODEL input control file ****
C
C     ...Read SOILMODEL input control file first time
      OPEN(INASCI,FILE=FUSR,STATUS='UNKNOWN',
     +     FORM='FORMATTED',READONLY)
      CALL PROCTL

      CLOSE(INASCI)
      OPEN(KDLIB,FILE=FLIB,STATUS='UNKNOWN',
     +     FORM='FORMATTED',READONLY)
      CALL LEACH(ALAMLCH)
      CLOSE(KDLIB)
C     ...Show USER the program status
      PRINT *,' *** Completed processing input data to produce output ',
     +        'leaching factors ***'
C
      IERR = 0
C     ...Set debugging/diagnostics file unit
      CALL DBERRUNI( NOUTFL )
C
C**** Begin program termination procedures ****
C
      CALL EXCPUS( RDUM )
      WRITE(NOUTFL,'(/A,F10.4,A)')' CPU time was',RDUM,' seconds'
      CALL QAPAGE(NOUTFL,'END')
      CLOSE(NOUTFL)
      STOP 'SOILMODEL Normal Completion'
C-----------------------------------------------------------------------
C**** END OF PROGRAM SOILMODEL (A1MAIN) ****
C-----------------------------------------------------------------------
      END


*COMDECK BLOCK
      BLOCK DATA BLOCK
C***********************************************************************
      INCLUDE 'IOCOM.INC/LIST'
      INCLUDE 'CAMCON_COMMON.INC/LIST'
      INCLUDE 'PARAMS.INC/LIST'
C*      INCLUDE 'INDEX.INC/LIST'
C*      INCLUDE 'DYNAME.INC/LIST'
      INCLUDE 'NUCDAT.INC/LIST'
      INCLUDE 'SOIL.INC/LIST'
      INCLUDE 'WATER.INC/LIST'

      CHARACTER*80 LINE1,LINE2,LINE3
      COMMON /L1/  LINE1
      COMMON /L2/  LINE2
      COMMON /L3/  LINE3

```

```
C       ...Dynamic array names (COMMON /DYNAME/)
C*        DATA DTYPES/
C*       $'INTEGER','INTEGER','LOGICAL','REAL'/
C*        DATA RNAMES/
C*       $'IDEBLK', 'NUMPRP', 'IASPRP', 'XMATPR'/
C*        DATA CNAMES/
C*       $'QAINFO','NAMELB','NMATPR'/

      DATA ITEMP1/1/ICDB/4/ISCREN/5/
     +     INASCI/2/KDLIB/11/,IOUTFL/8/

C         LASRIDX= Last index of REAL dynamic arrays [INTEGER]
C*        DATA LASCIDX/3/LASRIDX/4/

      DATA
     +LINE1/'The SOILMODEL program uses available data from research '/
     +LINE2/'papers to calculate leaching and erosion factors based on'/
     +LINE3/' characteristic soils for Armagosa Valley'/

      DATA PROGRM / 'SOILMODEL' /
      DATA PVERSN / 'A1.22' /
      DATA PDATE / '08/06/99' /
      DATA AUTHOR / 'Ron McCurley' /
      DATA SPONSR / 'Ron McCurley' /
      DATA NUMNUC/8/
      DATA NAMNUC/' C14','Cl36','Ni59','Ni63','Se79','Sr90','Zr93',
     +           'Mo93','Nb93m','Nb94','Pd107','Sb126','Sn126',' I129',
     +           'Cs137','Sm151','Bi210','Pb210',
     +           'Po210','Pu239','Ra225','Tc99','Th229','Pa231',
     +           ' U233',' U234',' U235',' U236',' U238',
     +           'Cm244',10*' '/
      DATA DEPTHS/0.15/RHOGRN/2.64E+03/RHOS/1.4E+03/THETA1/0.24/
     +     THETA2/0.29/THETA3/0.15/THETA4/0.23/
      DATA ET/10.0/IRRIG/20.0/PRECIP/15.0/
      DATA FRSATP/0.0054/,FRPRET/0.68/,FRSATI/0.2/,FRIRET/0.5/
      DATA MODEL/'BAES_SHARP'/
**********************************************************************
      END


*DECK GETKD
      SUBROUTINE GETKD(NUMNUC,NAMENUC,SOILTYPE,ELT,KD)
C*********************************************************************
C
      INCLUDE 'IOCOM.INC/LIST'
      INCLUDE 'PARAMS.INC/LIST'
      INCLUDE 'SOIL.INC/LIST'
      INTEGER IELT, INUC,  K,  NELT,  NUMNUC
      REAL KDSOIL(MAXNUC,MAXTYP), KD(*)
      CHARACTER*2 ELT(*)
      CHARACTER*8 NAMENUC(*),SOILTYPE
      CHARACTER*80 HEAD1, HEAD2
      LOGICAL FINDIT(MAXNUC)

      NTYP = 5
      IELT = 0
C     ...read 1st 2 lines of comments
      READ (KDLIB,1000,END=99) HEAD1
      READ (KDLIB,1000,END=99) HEAD2
 1000 FORMAT(A80)
   20 CONTINUE
      IELT = IELT + 1

      READ (KDLIB,1001,END=99) ELT(IELT), (KDSOIL(IELT,K),K=1,NTYP)
 1001 FORMAT(1X,A2,7X,5(E9.2,1X))
      GO TO 20
   99 NELT = IELT - 1
      DO 200 INUC=1,NUMNUC
        FINDIT(INUC) = .FALSE.
        DO 100 IELT=1,NELT
```

```
            IF(NAMENUC(INUC)(1:2).EQ.ELT(IELT) ) THEN
              FINDIT(INUC) = .TRUE.
              IF(SOILTYPE(1:4).EQ.'SAND') THEN
                KD(INUC)=KDSOIL(IELT,1)
              ELSEIF(SOILTYPE(1:4).EQ.'LOAM') THEN
                KD(INUC)=KDSOIL(IELT,2)
              ELSEIF(SOILTYPE(1:4).EQ.'CLAY') THEN
                KD(INUC)=KDSOIL(IELT,3)
              ELSEIF(SOILTYPE(1:4).EQ.'ORGA') THEN
                KD(INUC)=KDSOIL(IELT,4)
              ELSEIF(SOILTYPE(1:4).EQ.'BAES') THEN
                KD(INUC)=KDSOIL(IELT,5)
              ENDIF
            ELSEIF( (NAMENUC(INUC)(1:2).EQ.'U2' .OR.
     +               NAMENUC(INUC)(1:2).EQ.'I1' .OR.
     +               NAMENUC(INUC)(1:2).EQ.'C1') .AND.
     +               NAMENUC(INUC)(1:1).EQ.ELT(IELT)(1:1) ) THEN
              FINDIT(INUC) = .TRUE.
              IF(SOILTYPE(1:4).EQ.'SAND') THEN
                KD(INUC)=KDSOIL(IELT,1)
              ELSEIF(SOILTYPE(1:4).EQ.'LOAM') THEN
                KD(INUC)=KDSOIL(IELT,2)
              ELSEIF(SOILTYPE(1:4).EQ.'CLAY') THEN
                KD(INUC)=KDSOIL(IELT,3)
              ELSEIF(SOILTYPE(1:4).EQ.'ORGA') THEN
                KD(INUC)=KDSOIL(IELT,4)
              ELSEIF(SOILTYPE(1:4).EQ.'BAES') THEN
                KD(INUC)=KDSOIL(IELT,5)
              ENDIF
            ENDIF

 100      CONTINUE
          IF(FINDIT(INUC) .EQ. .FALSE.) THEN
             WRITE(NOUTFL,1002) NAMENUC(INUC)(1:2)
 1002        FORMAT(1X,'Could not find element ',A2,' in Kd library')
          ENDIF
 200    CONTINUE

        RETURN
        END


*DECK LEACH
        SUBROUTINE LEACH(ALAMLCH)
C**********************************************************************
C
C
        INCLUDE 'IOCOM.INC/LIST'
        INCLUDE 'PARAMS.INC/LIST'
        INCLUDE 'NUCDAT.INC/LIST'
        INCLUDE 'SOIL.INC/LIST'
        INCLUDE 'WATER.INC/LIST'
        INTEGER I,K
        REAL OVERWAT,THETA,SOILFAC,SOILH2O,UNTPRD,XNUMER
        REAL ALAMLCH(MAXNUC), KD(MAXNUC), UNTCNV(3)
        CHARACTER*(2) ELT(MAXNUC)

C*        UNTCNV/1.0E-2,1.0E3,1.0E-6/
        IF(UNITS_SOIL.EQ.'CGS' .AND. UNITS_H2O.EQ.'CGS') THEN
C       ...This is default!
          DO 10 I=1,3
            UNTCNV(I) = 1.0
   10     CONTINUE
        ELSEIF(UNITS_H2O.EQ.'ENG') THEN
c       ...using inches for water amounts
          UNTCNV(1) = 2.54
          DO 15 I=2,3
            UNTCNV(I) = 1.0
   15     CONTINUE
```

```
      ENDIF
      IF (SOILCAT(1:4).EQ.'SILT') THETA = THETA1
      IF (SOILCAT(1:4).EQ.'CLAY') THETA = THETA2
      IF (SOILCAT(1:4).EQ.'SAND') THETA = THETA3
      IF (SOILCAT(1:4).EQ.'ORGA') THETA = THETA4
      IF (SOILCAT(1:4).EQ.'BAES') THETA = THETA4

      UNTPRD=UNTCNV(2)*UNTCNV(3)
C     ..."overwatering term"
      OVERWAT = (PRECIP + IRRIG - ET)

C     ...alternative formulation from Jarzemba & Manteufel (modified from
C        Napier et al)
      IF(MODEL(1:5).EQ.'ALTER') THEN
         XNUMER = PRECIP*FRSATP*(1.0 - FRPRET) +
     +            IRRIG*FRSATI*(1.0 - FRIRET)
      ELSE
         XNUMER = OVERWAT*UNTCNV(1)
      ENDIF
      SOILH2O = THETA*DEPTHS
      SOILFAC = UNTPRD*RHOS/THETA
      WRITE(NOUTFL,1000)
 1000 FORMAT('      Precip  Irrig     ET    Water content Porosity  ',
     +         'Bulk den   Depth')
      WRITE(NOUTFL,1001) PRECIP,IRRIG,ET,THETA,POROSITY,RHOS,DEPTHS
 1001 FORMAT(7F10.2)
C     ...get kds for this soil type
      CALL GETKD(NUMNUC,NAMNUC,SOILCAT(1:4),ELT,KD)
      WRITE(NOUTFL,1002)
 1002 FORMAT('Elememt/nuclide kd   leaching factor'/)
C****calculate leaching factors
      DO 200 K=1,NUMNUC
        ALAMLCH(K) = XNUMER/(SOILH2O*(1.0 + SOILFAC*KD(K)))
        PRINT *, NAMNUC(K), KD(K),  ALAMLCH(K)
        WRITE(NOUTFL,1003) NAMNUC(K), KD(K),  ALAMLCH(K)
 1003   FORMAT(2X,A8,2(1PE9.2,2X))
  200 CONTINUE
      RETURN
      END


*DECK,PREPRO
      SUBROUTINE PREPRO( FUSR, FLIB, FOUT, FDBG )
C***********************************************************************
C
C  PURPOSE:     PREPRO input preprocessor which performs:
C               1.  QA functions
C               2.  Calls routine for parsing command line argUements
C                   which consists of filenames.  Those files are
C                   opened when appropriate or prompted for if not
C                   supplied on the command line or set to defaults.
C
C  AUTHOR:      Ron D McCurley
C
C  UPDATED:     07 May, 1999  --
C
C  CALLED BY:   SOILMODELIL {main program}
C
C  CALLS:       EXPARM
C               FILCMDLIN
C               WELCOM
C               TYPRQS
C               ISTRLEN
C               QABANNER
C               QAPAGE
C               QADOEDIS
C
C  ARGUMENTS:
C  ENTRY/
C   --common blocks
```

```
C   /IOCOM/ ($include 'IOCOM.INC')
C    NOUTFL  = Device no. of diagnostics/debUg output file
C              (Equilabrated to NOUTFL)
C   /L1/  Contains Line 1 of a 3-line program discription written out
C         following the program banner
C   /L2/  Contains Line 2 of a 3-line program discription written out
C         following the program banner
C   /L3/  Contains Line 3 of a 3-line program discription written out
C         following the program banner
C
C  LOCAL/
C     NFILES = Maximum nUmber of files on command line
C     BATCHF = Logical BATCH process flag
C     INTRAF = Logical INTERACTIVE process flag
C     ERRORF = Logical ERROR flag
C     HARD   = System hardware ID
C     SOFT   = System software ID
C     MODE   = BATCH(0) or INTERACTIVE(1) mode
C     KCSU   = Characters Units per base Unit
C     KNSU   = Numeric storage Units per base Unit
C     IDAU   = Units of storage which  define size of Unformatted
C              direct I/O  records 0=character, 1=nUmeric
C
C  EXIT/
C   --common block
C   /IOCOM/ ($include 'IOCOM.INC')
C    NOUTFL  = Device no. of diagnostics/debug output file
C
C   --through subroutine call
C    FUSR    = SOILMODEL Control Card Data filename
C    FCDB    =Calculational data base filename
C    FLIB    = SOILMODEL Kd library file
C    FOUT    = SOILMODEL program output file
C    FDBG    = SOILMODEL program diagnostics/debug filename
C
C-------------------------------------------------------------------
C234567
      IMPLICIT NONE
      INTEGER  ISTRLEN
      INCLUDE 'IOCOM.INC/LIST'
      COMMON /L1/  LINE1
      COMMON /L2/  LINE2
      COMMON /L3/  LINE3

      INTEGER       I,     IDAU,   KCSU,  KNSU, MODE, NFILES
      LOGICAL       EXIST, BATCHF, ERRORF, INTRAF
      CHARACTER*8   HARD,  SOFT
      CHARACTER*(*) FUSR,  FLIB, FOUT, FDBG
      CHARACTER*80  FILESP(4)
      CHARACTER*80  LINE1,LINE2,LINE3

C<><><><><><><><><><><><><>
C...BEGIN PROCEDURES...
C<><><><><><><><><><><><><>

C     ...Check if current run is BATCH or INTERACTIVE
C        BATCH -> messages to debug file
C        INTER -> messages to screen
      CALL EXPARM(HARD,SOFT,MODE,KCSU,KNSU,IDAU)
      IF (MODE .EQ. 0) THEN
         BATCHF = .TRUE.
      ELSE
         BATCHF = .FALSE.
      ENDIF

C     ...Get files names from command line
C        FILESP(1 to 4) are: FUSR, FLIB, FOUT, FDBG
C     ...If FUSR = 'default' all files will be defaulted, otherwise
C        they will be prompted for.  A blank response to the prompt will
C        also result in default file name.
```

```
      ERRORF = .FALSE
      CALL FILCMDLIN(4,NFILES,FILESP)
      FUSR = FILESP(1)
      FLIB = FILESP(2)
      FOUT = FILESP(3)
      FDBG = FILESP(4)

C     ...If any files specified on command line set INTRAF to false
      INTRAF = .TRUE.
      IF (NFILES .GT. 0) THEN
         INTRAF = .FALSE.
         BATCHF = .TRUE.
      ELSE
         INTRAF = .TRUE.
      ENDIF

      IF (INTRAF) THEN
C     ...INTERACTIVE:  Prompt for filenames

         CALL WELCOM
         WRITE(*,1000)
C
C        ------------------------------
C        SOILMODEL Control Card Data file
C        ------------------------------

  100    CALL TYPRQS(' Enter SOILMODEL Control Card Data filename'//
     +               ' <SOILMODEL.INP>',FUSR)
C        ...Null response implies default
         IF (FUSR .EQ. 'default' .OR. FUSR .EQ. 'DEFAULT' .OR.
     &       FUSR .EQ. ' ') FUSR = 'SOILMODEL.INP'
         INQUIRE(FILE=FUSR, EXIST=EXIST)
         IF (.NOT. EXIST) THEN
            WRITE(*,'(3A/)')
     &         ' FUSR=',FUSR(1:ISTRLEN(FUSR)),' does not exist'
            FUSR = ' '
            GOTO 100
         ENDIF

C        -------------------
C        COMPUTATIONAL data base
C        -------------------
C
C        ...Prompt User for COMPUTATIONAL data base
C* 200      CALL TYPRQS(' Enter COMPUTATIONAL data base filename'//
C*    +                 ' <POSTLHS.CDB>',FCDB)
C        ...Null response implies default
C*          IF (FCDB .EQ. 'default' .OR. FCDB .EQ. 'DEFAULT' .OR.
C*    &         FCDB .EQ. ' ') FCDB='POSTLHS.CDB'
C*          INQUIRE(FILE=FCDB, EXIST=EXIST)
C*          IF (.NOT. EXIST) THEN
C*             WRITE(*,'(3A/)')
C*    &           ' FCDB=',FCDB(1:ISTRLEN(FCDB)),' does not exist'
C*             FCDB = ' '
C*             GOTO 200
C*          ENDIF

C        ---------------------
C        SOILMODELIL output file
C        ---------------------
C
C        ...Prompt User for SOILMODEL output filename
         CALL TYPRQS(' Enter SOILMODEL output filename'//
     +               ' <LEACH.OUT>',FOUT)
C        ...Null response implies default
         IF (FOUT .EQ. 'default' .OR. FOUT .EQ. 'DEFAULT' .OR.
     &       FOUT .EQ. ' ') FOUT = 'LEACH.OUT'

C        ------------------------------
C        Diagnostics/Debug output file
```

```
C          ----------------------------
C
           WRITE(*,1100)
C          ...Prompt User for OPTIONAL diagnostics/debug file
           CALL TYPRQS(' Enter (optional) SOILMODEL diagnostics/debug'//
     +                 ' filename <SOILMODEL.DBG>',FDBG)
C          ...Null response implies default
           IF (FDBG .EQ. 'default' .OR. FDBG .EQ. 'DEFAULT' .OR.
     &         FDBG .EQ. ' ') FDBG='SOILMODEL.DBG'
           IF (FDBG(:3) .EQ. 'CAN' .OR. FDBG(:3) .EQ. 'can') THEN
C             ...Don't write a recoverable diagnostics/debug file
              NOUTFL = 6
              FDBG   = 'SOILMODEL.SCR'
           ELSE
              NOUTFL = 7
           ENDIF

        ELSE

C       ...Set Undefined files to defaults and check for existence
           IF (FUSR .EQ. 'default' .OR. FUSR .EQ. 'DEFAULT' .OR.
     &       (BATCHF .AND. FUSR .EQ. ' ') ) FUSR = 'SOILMOD.INP'
           INQUIRE(FILE=FUSR,EXIST=EXIST)
           IF (.NOT.EXIST) THEN
              WRITE(*,'(3A/)')
     &          ' FUSR=',FUSR(1:ISTRLEN(FUSR)),' does not exist'
              ERRORF = .TRUE.
           ENDIF

C*            IF (FCDB .EQ. 'DEFAULT' .OR. FCDB .EQ. 'default' .OR.
C*     &        (BATCHF .AND. FCDB .EQ. ' ') ) FCDB = 'POSTLHS.CDB'
C*            INQUIRE(FILE=FCDB,EXIST=EXIST)
C*            IF (.NOT.EXIST) THEN
C*               WRITE(*,'(3A/)')
C*     &           ' FCDB=',FCDB(1:ISTRLEN(FCDB)),' does not exist'
C*               ERRORF = .TRUE.
C*            ENDIF

           IF (FOUT .EQ. 'default' .OR. FOUT .EQ. 'DEFAULT' .OR.
     &       (BATCHF .AND. FOUT .EQ. ' ') ) FOUT = 'LEACH.OUT'

           IF (FDBG .EQ. 'default' .OR. FDBG .EQ. 'DEFAULT' .OR.
     &       (BATCHF .AND. FDBG .EQ. ' ') ) FDBG = 'SOILMODELIL.DBG'

           IF (FDBG(:3).EQ. 'CAN' .OR. FDBG(:3).EQ. 'can') THEN
C ...Don't write a recoverable diagnostics/debug file
              NOUTFL = 6
              FDBG   = 'SOILMODELIL.SCR'
           ELSE
              NOUTFL = 7
           ENDIF
        ENDIF

C       ...Open Diagnostics/Debug output file
        IF (NOUTFL.EQ.7) THEN
           OPEN(NOUTFL,FILE=FDBG,FORM='FORMATTED',STATUS='UNKNOWN')
        ELSEIF (NOUTFL.EQ.6) THEN
           OPEN(NOUTFL,FILE=FDBG,STATUS='SCRATCH')
        ENDIF

C       ...Write QA stuff
        CALL QABANNER(NOUTFL,LINE1,LINE2,LINE3)
        CALL QAPAGE(NOUTFL,' ')
        CALL QADOEDIS(NOUTFL,'*')

        WRITE(NOUTFL,1200)
        WRITE(NOUTFL,'(A)')'                    FILE ASSIGNMENTS'
        WRITE(NOUTFL,'(A)')'                    ----------------'
        WRITE(NOUTFL,'(A,A)')' SOILMODELIL Input Control FILE...........',
     +                       FUSR(1:40)
```

```
C*       WRITE(NOUTFL,'(A,A)')' COMPUTATIONAL Data Base FILE............',
C*      +                         FCDB(1:40)
        WRITE(NOUTFL,'(A,A)')' SOILMODEL output FILE.........',
     +                         FOUT(1:40)
        WRITE(NOUTFL,'(A,A)')' DIAGNOSTICS/DEBUG Output FILE.......',
     +                         FDBG(1:40)

C     ...Stop if ERRORF
      IF (ERRORF) THEN
         WRITE(NOUTFL,'(A)')' FILE SPECIFICATION ERROR(S)'
         STOP '*** FILE SPECIFICATION ERROR(S) IN PREPRO ***'
      ENDIF
      RETURN
C
C------------------ F O R M A T   S T A T E M E N T S -----------------
C
1000  FORMAT(/,' ...For <default filenames>, press RETURN',/)
1100  FORMAT(/,' ...To CANCEL optional files requested, respond',
     +       ' with: CANCEL',/)
1200  FORMAT(/,79('*'),/,1X,'(PREPRO)')
C
C-----------------------------------------------------------------------
C**** END OF subroutine PREPRO ****
C-----------------------------------------------------------------------
      END


*DECK,PROCTL
      SUBROUTINE PROCTL
C***********************************************************************
C***                                                               ****
C***              P_R_Ocess  input  C_on_T_ro_L File  module      ****
C***              - - -             -    -   -                    ****
C***********************************************************************
C
C  PURPOSE :    Reads the SOILMODEL input control file and RETURNS the
C               variables which will be modified from the template file
C               (i.e.--the sampled parameters).  May also return file
C.              names as used by INFIL
C
C  AUTHOR:      Ron D McCurley
C
C  UPDATED:     May, 1999
C
C  CALLED BY:   SOILMODEL
C
C  CALLS:       FFRDFLDS
C               DOECHO
C               RETRIE
C               QAABORT
C
C  ARGUMENTS:
C  ENTRY/
C   --common blocks
C    /IOCOM/ ($include 'IOCOM.INC')
C     INASCI = File unit of PRELHS input control file
C     NOUTFL = "                     diagnostics/debug file
C
C    /FFRDAT/ ($include 'FFRDAT.INC')
C     MFIELD = Max. no. of fields that Free-Field-Reader can process
C     NFORM  = Max. length of a CHARACTER data field
C
C  LOCAL/
C     CVALUE = CHARACTER values of the data fields
C     IERR   = INTEGER error flag
C     IOSTAT = INTEGER value for ANSI FORTRAN I/O status
C     IVALUE = INTEGER values of the data fields
C     KVALUE = Translation states of the data fields
C     NFIELD = Number of fields
C     RVALUE = REAL values of the data fields
```

```
C
C  EXIT/
C   --through subroutine call
C      NUMVAR = No. of LHS variables
C
C***********************************************************************
C234567
      IMPLICIT NONE
      INCLUDE 'IOCOM.INC/LIST'
      INCLUDE 'FFRDAT.INC/LIST'
      INCLUDE 'PARAMS.INC/LIST'

      INTEGER IERR, IOSTAT, NFIELD
      INTEGER IVALUE(MFIELD), KVALUE(MFIELD)
      REAL RVALUE(MFIELD)
      CHARACTER*(NFORM) CVALUE(MFIELD)
      CHARACTER*(8) KEYWORD

C<><><><><><><><><><><><><>
C...BEGIN PROCEDURES...
C<><><><><><><><><><><><><>

      IERR    = 0

C      ...Begin Scanning SOILMODEL control card data batch file
  10  CALL FFRDFLDS( INASCI, NOUTFL, ' ', MFIELD, IOSTAT,
     +              NFIELD, KVALUE, CVALUE, IVALUE, RVALUE )

  20  IF (IOSTAT.LT.0) THEN
C        ...End Of File for SOILMODEL control card input file found
         GOTO 100

      ELSEIF (IOSTAT.GT.0) THEN
C        ...Set the error flag, abort after EOF found
         IERR = IERR + 1
C        ...Read next record
         GOTO 10

      ELSEIF (IOSTAT.EQ.0) THEN

         IF ( KVALUE(1).EQ.-1 .OR.
     +        (KVALUE(1).EQ.0 .AND.CVALUE(1).EQ.'!') ) THEN
C           ...This is a comment line or a blank w/o information
C           ...Read next record
            GOTO 10

         ELSEIF( KVALUE(1).EQ.0 .AND. (CVALUE(1)(:4).EQ.'*NUC' .OR.
     +         CVALUE(1)(:6).EQ.'*MODEL' .OR.
     +         CVALUE(1)(:5).EQ.'*SOIL' .OR.
     +         CVALUE(1)(:6).EQ.'*WATER') ) THEN
C           ...Begin retrieving user data
            KEYWORD = CVALUE(1)(2:9)
            CALL RDPAR(IOSTAT, KEYWORD, NFIELD, KVALUE, CVALUE, IVALUE,
     +                 RVALUE)
C           ...Read next record
            GOTO 10
         ELSEIF( KVALUE(1).EQ.0.AND.CVALUE(1)(:4).EQ.'*END' )THEN
C           ...Found END of SOILMODEL control file
C           ...Abort reading user input
            GOTO 100

         ELSE
C           ...Meaningless data found
C           ...Read next record
            GOTO 10
         ENDIF
      ENDIF

 100  IF (IERR.GT.0) THEN
         WRITE(NOUTFL,*)' ***',IERR,' ERRORS FOUND IN PROCTL ***'
```

```
            CALL QAABORT('PROCTL')
         ENDIF
         RETURN
C-----------------------------------------------------------------------
C**** END OF SUBROUTINE PROCTL ****
C-----------------------------------------------------------------------
         END


*DECK RDPAR
         SUBROUTINE RDPAR( IOSTAT, KEYWORD, NFIELD, KVALUE, CVALUE, IVALUE,
        +                  RVALUE )
C***********************************************************************
C****                                                              ****
C****              R_ea_D  P_A_R ameter names module               ****
C****              -    -  - - -                                   ****
C***********************************************************************
C
C   PURPOSE:     Reads names of new SOILMOD input CONTROL parameters
C                as stored (with values) in CDB files as matched with
C                key user names (fixed or sampled)
C
C   AUTHOR:      Ron McCurley
C
C   UPDATED:     May 1999
C
C  CALLED BY:    PRCTRL
C
C  CALLS:        FREFLD
C                QAABORT
C
C  ARGUMENTS:
C  ENTRY/
C    --common blocks
C     /COMMIO/ ($includE 'GI1_COMMIO.INC')
C      ISCRAT = Device no. of PRESOILMOD scratch file
C      FILEIN = Device no. of PRESOILMOD input text file
C      NOUTFL = Device no. of diagnostics/debut output file
C
C     /PGENII/ ($includE 'GI1_PGENII.INC')
C
C    --through subroutine call
C      MFIELD = Max. no. of data fields FFR can process
C      IOSTAT = ANSI FORTRAN I/O error flag
C      NFIELD = No. of data fields read by FFR
C      KVALUE = INTEGER array of types of data fields read by FFR.
C      CVALUE = CHARACTER  array of data fields read by FFR.
C      IVALUE = INTEGER     "
C      RVALUE = REAL        "
C
C  LOCAL/
C      none
C
C  EXIT/
C    --common blocks
C     /I/ ($includE 'I.INC') ???
C      ...REAL variables
C
C    --through subroutine call
C      MFIELD = Max. no. of data fields FFR can process
C      IOSTAT = ANSI FORTRAN I/O error flag
C      NFIELD = No. of data fields read by FFR
C      KVALUE = INTEGER array of types of data fields read by FFR.
C      CVALUE = CHARACTER  array of data fields read by FFR.
C      IVALUE = INTEGER     "
C      RVALUE = REAL        "
C
C***********************************************************************
C234567
         IMPLICIT NONE
```

```
      INCLUDE 'FFRDAT.INC/LIST'
      INCLUDE 'IOCOM.INC/LIST'
      INCLUDE 'PARAMS.INC/LIST'
      INCLUDE 'NUCDAT.INC/LIST'
      INCLUDE 'SOIL.INC/LIST'
      INCLUDE 'WATER.INC/LIST'

      INTEGER I, IERR, INUC, IOSTAT, K, NFIELD
      INTEGER IVALUE(*), KVALUE(*)

      REAL RVALUE(*), THETA

      CHARACTER*(NFORM) CVALUE(*)
      CHARACTER*(*) KEYWORD

C<><><><><><><><><><><><><>
C...BEGIN PROCEDURES...
C<><><><><><><><><><><><><>

      IERR   = 0
C     ...Read data for parameter replacement into new SOILMOD input control
C        file
   10 CALL FFRDFLDS( INASCI, NOUTFL, ' ', MFIELD, IOSTAT,
     +               NFIELD, KVALUE, CVALUE, IVALUE, RVALUE )

   20 IF (IOSTAT.LT.0) THEN
C        ...End Of File for SOILMOD control card input file found
         WRITE(NOUTFL,1001)
         WRITE(NOUTFL,1002)
         WRITE(NOUTFL,1001)
         GO TO 100

      ELSEIF (IOSTAT.GT.0) THEN
C        ...Set the error flag, abort after EOF found
         IERR = IERR + 1
C        ...Read next record
         GOTO 100

      ELSEIF (IOSTAT.EQ.0) THEN
        IF (KEYWORD(1:3).EQ.'NUC') THEN
C          ...get nuclide names
           IF ( KVALUE(1).EQ.-1 .OR.
     +        (KVALUE(1).EQ.0 .AND.CVALUE(1).EQ.'!')) THEN
C          ...This is a comment line or a blank w/o information
C          ...Read next record
             GOTO 10

           ELSEIF(KVALUE(1).EQ.0.AND.CVALUE(1)(:4).EQ.'NAME' .OR.
     +          CVALUE(1)(1:4).EQ.'name' ) THEN

             DO 30 I=2,NFIELD
               INUC = I-1
               NAMNUC(INUC)=CVALUE(I)(1:8)
   30        CONTINUE
             NUMNUC = NFIELD-1
           ELSE
C            ...Found meaningless data
               WRITE(NOUTFL,*)'***found unexpected meaningless data ',
     +                        'may be a problem in user input file!****'
C*            NAME_NUC =.TRUE.

           ENDIF
C            ...return to read next keyword
           GOTO 999
         ELSEIF (KEYWORD(1:5).EQ.'MODEL') THEN
           IF ( KVALUE(1).EQ.-1 .OR.
     +        (KVALUE(1).EQ.0 .AND.CVALUE(1).EQ.'!')) THEN
C          ...This is a comment line or a blank w/o information
C          ...Read next record
             GOTO 10
```

```
            ELSEIF ( KVALUE(1).EQ.0 ) THEN
C             ...Begin retrieving soil parameter data
C                loop over remaining words in this field
              IF(CVALUE(1)(1:5).EQ.'WATER') MODEL = CVALUE(2)(1:8)
            ENDIF
            GOTO 999
          ELSEIF (KEYWORD(1:4).EQ.'SOIL') THEN
            IF ( KVALUE(1).EQ.-1 .OR.
     +         (KVALUE(1).EQ.0 .AND.CVALUE(1).EQ.'!')) THEN
C           ...This is a comment line or a blank w/o information
C           ...Read next record
              GOTO 10
            ELSEIF ( KVALUE(1).EQ.0 ) THEN
C             ...Begin retrieving soil parameter data
C                loop over remaining words in this field
              DO 40 I=1,NFIELD,2
                IF(KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'TYPE' .OR.
     +             CVALUE(I)(:4).EQ.'type') THEN
                   SOILCAT(1:4) = CVALUE(I+1)
                ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'DENS' .OR.
     +                 KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'dens') THEN
                   RHOS = RVALUE(I+1)
                ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:5).EQ.'POROS' .OR.
     +                 KVALUE(I).EQ.0.AND.CVALUE(I)(:5).EQ.'poros') THEN
                   POROSITY = RVALUE(I+1)
                ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:5).EQ.'DEPTH' .OR.
     +                 KVALUE(I).EQ.0.AND.CVALUE(I)(:5).EQ.'depth') THEN
                   DEPTHS = RVALUE(I+1)
                ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:5).EQ.'WATER' .OR.
     +                 KVALUE(I).EQ.0.AND.CVALUE(I)(:5).EQ.'water') THEN
                   THETA = RVALUE(I+1)
                ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'UNIT' .OR.
     +                 KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'unit') THEN
                   UNITS_SOIL = CVALUE(I+1)(1:8)
                ELSE
C               ...Found meaningless data
                   WRITE(NOUTFL,*)'***found unexpected meaningless data',
     +                       ' may be a problem in user input file!***'
                ENDIF
   40         CONTINUE
C             ...
            ENDIF
          GOTO 100

          ELSEIF (KEYWORD(1:5).EQ.'WATER') THEN
C             ...Begin retrieving water parameter data
C                loop over remaining words in this field
             DO 60 I=1,NFIELD,2
              IF(KVALUE(I).EQ.0.AND.CVALUE(I)(:6).EQ.'PRECIP' .OR.
     +              KVALUE(I).EQ.0.AND.CVALUE(I)(:6).EQ.'precip') THEN
                 PRECIP = RVALUE(I+1)
              ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'IRRI' .OR.
     +              KVALUE(I).EQ.0.AND.CVALUE(I)(:4)..EQ.'irri') THEN
                 IRRIG = RVALUE(I+1)
              ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'EVAP' .OR.
     +              KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'evap') THEN
                 ET = RVALUE(I+1)
              ELSEIF(KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'UNIT' .OR.
     +              KVALUE(I).EQ.0.AND.CVALUE(I)(:4).EQ.'unit') THEN
                 UNITS_H2O = CVALUE(I+1)(1:8)
              ELSE
C             ...Found meaningless data
                 WRITE(NOUTFL,*)'***found unexpected meaningless data ',
     +                        'may be a problem in user input file!***'
              ENDIF
   60      CONTINUE
C          ...
           GOTO 999
          ELSE
C         ...Found meaningless data
```

```
            WRITE(NOUTFL,*)' ***found unexpected meaningless data ',
     +                     'may be a problem in user input file!***'
C           ...Read next record
            GOTO 10
          ENDIF
C         ...Read next record
          GOTO 10
      ENDIF

 100  CONTINUE
      IF (SOILCAT(1:4).EQ.'SILT') THETA1 = THETA
      IF (SOILCAT(1:4).EQ.'CLAY') THETA2 = THETA
      IF (SOILCAT(1:4).EQ.'SAND') THETA3 = THETA
      IF (SOILCAT(1:4).EQ.'ORGA') THETA4 = THETA
      IF (SOILCAT(1:4).EQ.'BAES') THETA4 = THETA

C
 999  CONTINUE
      RETURN
 1001 FORMAT('*******************************************')
 1002 FORMAT('WARNING! '/
     +       'Encountered unexpected end of user input'/
     +       'May be bad file! ')
C-----------------------------------------------------------------------
C**** END OF SUBROUTINE RDPAR  ****
C-----------------------------------------------------------------------
      END


*DECK,TYPRQS
      SUBROUTINE TYPRQS( PROMPT, ISTRNG )
C***********************************************************************
C
C  PURPOSE:     Outputs a request for a character string using PROMPT
C               and then inputs the character string (ISTRNG) in an
C               interactive session.
C
C  AUTHOR:      Rob Rechard
C
C  UPDATED:     June 1985
C               July 1987          --Ginger Wilkinson
C               15 February, 1989  --Jonathan S. Rath made more generic
C
C  CALLED BY:   PREPRO
C
C  ARGUMENTS:
C  ENTRY/
C   --through subroutine call
C     PROMPT  = Message to print on the screen
C
C  EXIT/
C   --subroutine call
C     ISTRNG  = Character string read
C
C***********************************************************************
C234567
      IMPLICIT NONE
      CHARACTER*(*) ISTRNG, PROMPT
      WRITE(*,1000)PROMPT
   10 READ(*,'(A)',END=20,ERR=30) ISTRNG
      RETURN

   20 WRITE(*,2000)
      GOTO 10
   30 WRITE(*,3000)
      GOTO 10

C--------------- F O R M A T   S T A T E M E N T S ------------------
1000  FORMAT(A,' >>')
2000  FORMAT(' ***NO DATA--TRY AGAIN***')
```

```
3000  FORMAT(' ***BAD CHARACTER STRING--TRY AGAIN***')
C-----------------------------------------------------------------------
C**** END OF SUBROUTINE TYPRQS ****
C-----------------------------------------------------------------------
      END


*DECK,WELCOM
      SUBROUTINE WELCOM
C***********************************************************************
C
C  PURPOSE:     Produces Instructions for main program usage
C
C  PROGRAMMER:  Jonathan S. Rath
C
C  UPDATED:     24 May, 1989 --First Ed.
C
C  CALLED BY:   PREPRO
C
C  CALLS:       QABANNER
C
C  ARGUMENTS:
C  ENTRY/
C    --common blocks
C
C    /QACOMMON/
C      PROGRM  =  The program name (CHAR*12)
C      PVERSN  =  The program version number (CHAR*8)
C
C    /L1/  Contains Line 1 of a 3-line program discription written out
C          following the program banner
C    /L2/  Contains Line 2 of a 3-line program discription written out
C          following the program banner
C    /L3/  Contains Line 3 of a 3-line program discription written out
C          following the program banner

C  LOCAL/
C      IOUT    =  Device number of output file
C
C  EXIT/
C       none
C
C***********************************************************************
C234567

      IMPLICIT NONE

      INCLUDE 'CAMCON_COMMON.INC/list'

      INTEGER IOUT
      CHARACTER*1  CHAR
      CHARACTER*80 LINE1,LINE2,LINE3
      COMMON /L1/  LINE1
      COMMON /L2/  LINE2
      COMMON /L3/  LINE3
      DATA IOUT/5/

C<><><><><><><><><><><><>
C...Begin Procedures...
C<><><><><><><><><><><><>

      OPEN(IOUT,FILE='SYS$OUTPUT',FORM='FORMATTED',STATUS='UNKNOWN')
      CALL QABANNER(IOUT,LINE1,LINE2,LINE3)
      WRITE(IOUT,1000)
C     ...Abort PROGRM program execution ?
      WRITE(IOUT,1200)PROGRM,PVERSN
      READ(IOUT,'(A)')CHAR
      IF(CHAR.NE.' ')THEN
        STOP '**** USER ABORTED EXECUTION IN SUBROUTINE WELCOM ****'
      ENDIF
```

```
      CLOSE(IOUT)
      RETURN
C
C--------------- F O R M A T   S T A T E M E N T S -----------------
C
1000  FORMAT(///
     +'***************************************************************'/
     +'    PREINFIL: PRE-processor for INFIL input control file    '/
     +'***************************************************************'///
     +' Following are prompts for'//
     +'         (1) Filename of PREINFIL control input file'/
     +'         (2) Filename of Computational Data Base to be read'/
     +'         (3) Filename of Template INFIL input control file '/
     +'         (3) Filename of PREINFIL generated INFIL input file'/
     +'         (4) (OPTIONAL) Filename of PREINFIL diagnostics/debug'/
     +'             file'//,
     +'***************************************************************'/)
C
1200  FORMAT(/79('*'),///1X,'To CONTINUE program ',A,' V',A,' press',
     +          ' the RETURN key.',/1X,'To ABORT program, type the word',
     +          ' ABORT')
C
C-------------------------------------------------------------------
C**** END OF SUBROUTINE WELCOM ****
C-------------------------------------------------------------------
      END
```